Sustainable Food Processing

Edited by Brijesh K. Tiwari, Tomas Norton and Nicholas M. Holden

WILEY Blackwell

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Contents

List of Contributors vii

List of Figures xi

List of Tables xv

1 Introduction 1
Brijesh K. Tiwari, Tomas Norton and Nicholas M. Holden

Section 1: Principles and Assessment 9

2 Current Concepts and Applied Research in Sustainable Food Processing 11
Wayne Martindale, Tim Finnigan and Louise Needham

3 Environmental Sustainability in Food Processing 39
Poritosh Roy, Takahiro Orikasa, Nobutaka Nakamura and Takeo Shiina

4 Life Cycle Assessment and Sustainable Food Processing 63
Nicholas M. Holden and Ming-Jia Yan

5 Environmental Impact Assessment (EIA) 93
Colm D. Everard, Colette C. Fagan and Kevin P. McDonnell

6 Risk Analysis for a Sustainable Food Chain 103
Uma Tiwari and Enda Cummins

Section 2: Food Processing Applications 125

7 Dairy Processing 127
Anwesha Sarkar, Lakshmi Dave, Anant Dave and Shantanu Das

8 Meat Processing 169
Daniel M. Anang

9 Seafood Processing 195
Christian James, Graham Purnell and Stephen J. James

10 Sustainable Processing of Fresh-Cut Fruit and Vegetables 219
Francisco Artés-Hernández, Perla A. Gómez, Encarna Aguayo, Alejandro Tomás-Callejas and Francisco Artés

11 Sustainable Food Grain Processing 269
Anil Kumar Anal, Imran Ahmad, Jiraporn Sripinyowanich and Athapol Noomhorm

12 Sustainable Brewing 295
Kasiviswanathan Muthukumarappan and N. N. Misra

13 Sustainable Processed Food 313
Anne Sibbel

Section 3: Food Manufacturing Operations 337

14 Concept of Sustainable Packaging System and Its Development 339
Jasim Ahmed and Tanweer Alam

15 Sustainable Cleaning and Sanitation in the Food Industry 363
Tomas Norton and Brijesh K. Tiwari

16 Energy Consumption and Reduction Strategies in Food Processing 377
Lijun Wang

17 Water Consumption, Reuse and Reduction Strategies in Food Processing 401
Hülya Ölmez

18 Food Industry Waste Management 435
Belarmino Adenso-Díaz and Carlos Mena

19 Sustainable Cold Chain 463
Stephen J. James and Christian James

Section 4: Food Distribution and Consumption 497

20 National and International Food Distribution: Do Food Miles Really Matter? 499
David Coley, Michael Winter and Mark Howard

21 Sustainable Global Food Supply Networks 521
Ultan McCarthy, Ismail Uysal, Magalie Laniel, Gerard Corkery, Francis Butler, Kevin P. McDonnell and Shane Ward

22 Sustainable Food Consumption 539
Kritika Mahadevan

Index 557

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List of Figures

Figure 3.1 Relationship between relative LCI and loss in food supply (Shiina, 1998) (The relative LCI = (x1 + x2)/x3; where x1 is production LCI, x2 is post-harvest LCI and x3 is production LCI without loss, if x2 = x3/loss in decimal).
Figure 3.2 Trend of food supply from different sources in different regions.
Figure 3.3 Trend of energy intake from different food source in Japan (*includes potatoes, legumes, seeds and nuts).
Figure 3.4 Trend of protein intake from different food source in Japan (*includes potatoes, legumes, seeds and nuts).
Figure 3.5 Food supply and intake in Japan.
Figure 3.6 Food supply in different countries and in the world.
Figure 3.7 Relationship between GDP and food supply in Japan and USA.

Figure 4.1 An example of a generic cradle-to-grave/cradle LCA system.
Figure 4.2 Schematic of the system included in the Environmental Product Declaration for liquid milk.
Figure 4.3 Schematic representation of a typical design process.
Figure 4.4 Schematic representation of attributional LCA (left) and consequential LCA (right).
Figure 4.5 Schematic representation of the general requirements for defining the system boundary, processes stages and flows for LCA following ISO standards.
Figure 4.6 Schematic illustration of allocation (top) vs. system expansion with avoided burden (bottom).
Figure 4.7 Schematic of broad general processes for LCI.
Figure 4.8 Schematic of processes closely related to mechanism for LCI.
Figure 4.9 Material balance for processes.
Figure 4.10 The link between emissions, midpoint impacts and endpoint impacts.
Figure 4.11 Schematic representation of the food chain and the place of processing within it.

Figure 5.1 Schematic of the European Union (EU) Environmental Impact Assessment (EIA) process.

Figure 6.1 Components of risk analysis.
Figure 6.2 Qualitative risk matrix.

Figure 6.3 Schematic representation of the possible entry route for chemical hazards (dioxins, PCBs and PCDDs) in human food.
Figure 6.4 Steps in risk management.
Figure 6.5 Risk analysis for sustainability in the food chain.

Figure 7.1 Schematic diagram showing milk processing, from the farm until the product reaches the consumer.
Figure 7.2 Flow chart of dairy processing operations.
Figure 7.3 Flow chart of the operations in the manufacture of fluid milk.
Figure 7.4 Flow chart of the operations in the manufacture of cream and butter.

Figure 8.1 Meat processing and associated operations and greenhouse gases emissions.
Figure 8.2 Flow diagrams of livestock slaughter and waste generation.
Figure 8.3 Flow diagram of poultry slaughter and waste generation.

Figure 10.1 Usual steps and unit operations for processing and commercialization of fresh-cut plant produce.
Figure 10.2 Estimation of V_{max} values of in vitro PPO activity as a function of initial O2 concentration, using chlorogenic acid as substrate (bars indicate 95% confidence limits).

Figure 11.1 Rice processing and its co-products.

Figure 12.1 Process Flow chart of Instant Coffee Production.
Figure 12.2 Traditional Brewing Process.
Figure 12.3 Operations and resources involved in the production of beer.
Figure 12.4 Value added brewery process.
Figure 12.5 Water network, heating and cooling system in a typical brewery. Steam is used for mashing and boiling; part of the waste vapour produced during boiling is utilized for wort preheating, while the unused waste vapour is ejected to the atmosphere. Within the packaging area, the steam is used by a Clean-in-Place (CIP) system for the sterilization of filling lines and for pasteurization. Cooling is needed for the preparation of clarified wort for fermentation (chilled water), and during fermentation and maturation.

Figure 14.1 The four levels and principles of sustainable packaging.
Figure 14.2 Life Cycle Assessment (LCA) flow diagram for fruit juice packed in polylactide based nanopackaging.
Figure 14.3 Schematic illustration of the food supply.

Figure 15.1 Sinner's circle illustrating the energy required to remove soil from a surface with contribution from time, temperature (temp.), detergent (chem.), and mechanical force (mech.).
Figure 15.2 Results from cleaning of a T-piece that was carried out during the PathogenCombat project (PathogenCombat, 2010). Modelling results of predicted wall shear stress are shown in the top left and right corners with the experimental evidence in the figure below. In this experiment the orange agar depicts uncleaned zones whereas the purple agar represents the clean areas.

Figure 16.1 Delivered energy consumption by the type of fuels in the food manufacturing industry in the United State in 2002.
Figure 16.2 Energy consumption by the end users.
Figure 16.3 Schematic diagram of a liquid-liquid heat pump system for pasteurization of milk.

Figure 17.1 Global water resources.
Figure 17.2 The dependence of sectoral breakdown of annual freshwater withdrawals to income levels based on the values for the year 2009.
Figure 17.3 Water fluxes within boundaries of the food and beverage industry.
Figure 17.4 Determination of the historical technological change in water intensity of the manufacturing of food products, beverages and tobacco, considering two time periods (1953–1983 and 1983–1998).
Figure 17.5 Scheme for establishing a HACCP plan for reconditioning of process water to be reused in the food industry.
Figure 17.6 A zero liquid discharge scheme.
Figure 17.7 Water utilization systems in process plants.
Figure 17.8 Three-step procedures for SWE minimization.
Figure 17.9 Types of batch water using processes: (a) truly batch, (b) semi-continuous.

Figure 18.1 Tonnes of total food waste generation in manufacturing, household and catering in EU27 during 2006.
Figure 18.2 Per capita tonnes of total food waste generation in EU27 during 2006.
Figure 18.3 The food supply chain.
Figure 18.4 Food processing unit operations and associated waste.
Figure 18.5 The waste hierarchy.
Figure 18.6 Waste ranges for different products.

Figure 19.1 Energy consumption of refrigeration systems of transport vehicles.
Figure 19.2 Energy used in refrigeration systems in catering establishment pre and post refit.
Figure 19.3 Energy used prior to and after installation of fibre optic lighting on retail display.
Figure 19.4 Energy consumed by different types of CSCs in different types of catering establishments.
Figure 19.5 Electrical energy consumption per week in 2009.

Figure 20.1 Main sources of fossil fuel related carbon emissions and flow of product for the large-scale system. Only those with double borders are considered and used to form Md.
Figure 20.2 Main sources of fossil fuel related carbon emissions and flow of product for the small-scale system. Only those with double borders are considered and used to form Md.
Figure 20.3 CO_2 emissions generated by different modes of freight transport.
Figure 20.4 Mode and location for UK food transport.
Figure 20.5 A selection (for clarity) of source and mode-weighted emissions (gCO_2/kg imported) estimated for a single farm in each of the 26 countries studied. (Note although the locations are identified by country, they are specific to the farm and supplier used by the retailer in each country and

they should not necessarily be seen as representative of the whole country.)
Figure 20.6 Scatter plot of distance vs. CO_2 emissions for international sourcing routes (and all 55 farms in the study), note the low R2 value, indicating a poor correlation.
Figure 20.7 Scatter plot of distance vs. CO_2 separated into routes relying predominantly on road transport and those relying predominantly on sea.
Figure 20.8 Visual representation of the CO_2 emissions associated with the import of fresh produce into the UK, some source countries have been separated into regions to represent different locations within the country itself.

Figure 21.1 Illustration of biometric traceability systems for animals and poultry: a) facial recognition of sheep, b) muzzle identification of cattle, c) retina identification of sheep and d) comb identification of poultry.

Figure 22.1 Four dimensions of food security.
Figure 22.2 Barriers to sustainable food consumption.
Figure 22.3 Per capita food losses and waste, at consumption and pre-consumption stages, in different regions (FAO, 2011).

List of Tables

Table 2.1	Trends in production for selected agricultural products obtained from FAOSTAT (2011) data that provide key ingredients in the food production system
Table 4.1	Summary of example environmental assessment tools that can be used for the food chain indicating the focus, scale at which it can be deployed and overlap with economic analysis
Table 4.2	Examples of LCA databases (open access and commercial) that can be used to build LCI data tables for specific LCA projects
Table 4.3	Examples of LCIA methodologies that can be used for LCA projects
Table 4.4	Guiding principles of the Food SCP Round Table
Table 6.1	Main principles of food safety risk management
Table 8.1	*Per capita* meat consumption (Kg per person) in selected countries
Table 8.2	Meat production and the meat trade (import and export) of selected countries
Table 8.3	Characteristics of wastewater generated from livestock and poultry slaughter
Table 8.4	Positive and negative nutrition and health aspects of consumption of processed meat
Table 8.5	Water usage and wastewater generation from the production of salami and sausages
Table 9.1	Energy performance of industrial fisheries
Table 9.2	Energy required to manufacture ice kWh/tonne
Table 9.3	Relative contribution (%) of ice production to AP, ADP, EP, GWP, OLP, METP in relation to the catching of Atlantic mackerel
Table 11.1	Approximated composition of paddy and its milling fractions at the moisture content of 14%w.b
Table 11.2	Vitamin and mineral contents of paddy and its milling fractions at the moisture content of 14%w.b
Table 11.3	Effects of the proposed techniques on insect mortality, milled rice quality and the storability of packaged rice
Table 12.1	Cellular wall constituents and structural polysaccharides (%) in coffee pulp

Table 12.2 Amino acid content of coffee pulp protein compared to other important protein sources
Table 12.3 Composition (%) of mucilage

Table 14.1 The principle and levels of sustainable package
Table 14.2 General strategies and key performance indicators for the design, procurement or evaluation of sustainable packaging
Table 14.3 Life cycle environmental impact indicators reported in PIQET
Table 14.4 The environmental impact from food, F, and environmental impact from packaging, T, and the ratio F/T

Table 16.1 Energy use and indicator in different food manufacturing sectors in the United States in 2006
Table 16.2 Energy use for production of different food products in the Netherlands in 2001
Table 16.3 Potential energy savings in British industry
Table 16.4 Summary of some energy savings identified in a Nestle factory

Table 17.1 Water quantity and quality as a function of use by food and beverage industry
Table 17.2 Industry shares of emissions of organic pollutants measured in terms of BOD (% of total) in 2007
Table 17.3 Overview of representative unit processes and operations used in water reclamation
Table 17.4 Wastewater disinfection technologies
Table 17.5 Water consumption and wastewater generation rates in food industry
Table 17.6 Examples of water conservation and effluent minimization practices for food processing industries
Table 17.7 Advantages and limitations of disinfection methods proposed for fresh-cut organic vegetables
Table 17.8 Drivers, barriers, challenges and solutions to implementation of water reuse in the food industry

Table 18.1 Classification of food waste based on Lebersorger and Schneider (2011) and WRAP (2011)
Table 18.2 Retail formats and causes of waste
Table 18.3 Main causes of wastage
Table 18.4 Summary of causes and main links of the food supply chain affected
Table 18.5 Retailer's waste hierarchy for product disposal

Table 19.1 Refrigeration requirements and losses due to lack of refrigeration
Table 19.2 Transport emissions estimated for transporting food from its source to UK stores and on to consumers homes
Table 19.3 Energy consumed by each cold store
Table 19.4 Best estimate of the top ten food refrigeration processes ranked in terms of their potential for total energy saving (basis of estimations provided on www.grimsby.ac.uk/documents/defra/usrs-top10users.pdf)
Table 19.5 Specific energy required (MJ/t) to chill, freeze and process (cutting and deboning) meat
Table 19.6 Characteristics and applications of new/alternative refrigeration technologies
Table 19.7 Refrigeration loads (kW) in factory

Table 20.1 The negative externalities of UK agriculture (year 2000). For comparison the UK's GDP in 2005 was around £1.2T
Table 20.2 National Travel Survey data about personal travel for shopping in the UK, 1998–2000
Table 20.3 Carbon emissions from the large-scale box system
Table 20.4 Sources of Embedded Energy in Box System
Table 20.5 Emission factors used in the study

Table 22.1 Undernourishment in the developing regions 1990–92 to 2010–12
Table 22.2 Global and regional per capita food consumption (kcal per capita per day)
Table 22.3 Rating system developed by Marine Conservation Society as advice for choosing the most environmentally sustainable fish
Table 22.4 Summary of impacts of framework guidelines for 'sustainable' and healthy diets

1 Introduction

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1.1 Introduction

Sustainability is defined as '*to endure*', but this definition does not properly capture the sense in which it is used globally to address how human activity impacts on societies, economics and the environment. The terms 'sustainability' and 'sustainable development' have increasingly appeared 'on the radar' of many industries (Leadbitter, 2002). They were first coined by the Brundtland Commission (formally the World Commission on Environment and Development of the United Nations) in 1983. The Brundtland Commission defined "Sustainable Development" as the 'social and economic advance to assure human beings a healthy and productive life, but one that did not compromise the ability of future generations to meet their own needs'. When related to food processing, this concept suggests that the process should:

i. be based on raw materials that can be produced on an ongoing basis without undue environmental, social or economic harm;
ii. not be reliant, in the long-term, on finite energy sources; and
iii. produce products that will not adversely affect human health.

Maintaining a sustainable food processing chain is now more important to food producers than ever before. With global inequalities becoming more

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pronounced, ingredient costs climbing, and global change becoming a major political issue, food producers must now take the opportunity to address environmental concerns, social responsibility and economic viability when shaping their food processing techniques for the future. However, it must also be said that food processing faces numerous challenges in changing economic and environmental conditions. Therefore, new ways of meeting the needs of the present without comprising future viability have to be embraced by the food industry.

The achievement of rational energy use, sufficient food production, avoiding needless food waste and appropriate management of necessary environmental impacts underpins well-being, health and longevity for human populations and the world's environment. There is perhaps a trend emerging in the agrifood sector to try to simplify the 'sustainability question'. Indicators such as carbon footprint, energy audit and nutritional indices are variously used to support claims of sustainability, but these mono-dimensional methods cannot really address the complexity inherent in sustainability. An indicator of the sustainability of food systems such as the ratio of energy outputs in terms of the energy content of a food product (calories) to the energy input (energy required in food production and processing), with the latter being all the energy consumed in producing, processing, packaging and distribution, might be useful, but ignores the question of the value of the calories provided (and even whether these should be expressed on a raw or cooked basis). It also ignores the contribution of renewable energy to the energy inputs. The quantification of this metric might be regarded as essential for food producers looking to make a positive economic and environmental impact in the future, especially given that the food industry is one of the world's largest users of energy, and considering this one index will only address one dimension of sustainability. Greenhouse gas emissions, which have increased remarkably in recent decades have resulted in global warming, perhaps the most serious problem that humankind faces today. Food production, preservation and distribution contribute greatly to total global greenhouse gas emission. These impacts are commonly described using carbon footprint, but such a measure provides no indication of the social or economic dimensions of sustainability, or even non-correlated environmental impacts. It is important that the food industry does not just focus on simple indicators of sustainability that are relatively easy to calculate, have appeal to governments and the public, but do not properly address the many dimensions of sustainability. The threat of limited food security has been highlighted globally by the coincidence of environmental degradation, economic growth, population increase and climate change. All these factors have impacted on the world food system (Headey and Fan, 2008). Questions about sustainability and corporate social responsibility are being seriously considered and implemented in many countries around the globe. Given that these highlighted concerns cause a considerable challenge

for food processors and technologists, there is a requirement for detailed industrially relevant information that addresses these challenges.

1.2 Key drivers for sustainable food processing

1.2.1 Food security

Food production and processing is essential to the global economy and to the health and welfare of its citizens. The core objective of global food security is to match the supply of food with the nutritional demand of the world's burgeoning population (to reach 9 billion by 2050) in the most sustainable way possible (i.e. in a way that can continue for centuries). Through technological progression in food storage and transportation it has become possible to ensure that reliable food supply chains are operational all over the world. These food chains reflect a balance between the commodity value of food and the human right to nutrition. Unless these sometimes-contradictory pressures can be balanced, sustainable food supply and food security cannot be achieved.

1.2.2 Population health

It is difficult to envisage how to link processing to sustainability and then to health, but this is going to be a key driver in the future. The economic and social cost of supplying excessive amounts of processed food to limited sections of the global population will perhaps ultimately be the main driver of the transformation of our current food chains from being predominantly market driven (in terms of consumer spending and a desire for cheap food) to being sustainability driven, where the cost to national economies of providing the inappropriately processed food to a society is regarded as unacceptable, and we transition to eating geographically appropriate, higher quality foods. Societal demand for safe, traceable food also has the potential to impact on the types of food processing and ingredient redistribution that occurs in the food chain.

1.2.3 Social justice

The welfare and rights of humans (and animals) at all stages of the food chain (production, processing, distribution, consumption and waste management) are usually not thought of in terms of sustainability. Demand for large volumes of low cost, processed foods has implications for those supplying the raw materials and those consuming the products that emerge. In this book we will not consider these issues in detail, but as governments increasingly seek value for the farmer (in some parts of the world) and

acceptable health costs, social justice will become an increasingly important driver of food system sustainability.

1.2.4 Global change

While it is generally known that agricultural production is a significant greenhouse gas emitter it must also be recognized that food processing and the distribution sector contribute to emissions, via energy used in processing, transportation and also the emission from food waste dumped in landfills. As well as climate change, the knock on effect of change in water availability is also a significant driver for sustainable food processing. Changing global climates means that more innovation is required in cooling and refrigeration technologies to extend the shelf-life of perishable foods without using too much energy and more efficient water use. The potential impact of global change on water availability will present challenges to the food processing industries, particularly of developing countries, where natural drying methods are still employed.

1.2.5 Resource depletion

There are many resource depletion impacts arising from food consumption, some of which, while not directly caused by processing, are driven by processing because of demand for ingredients with specific characteristics on a year round basis. Within the whole food system depletions of water, soil, nutrients, air and water quality and energy are all quite obvious. Food processing, and the demand for processed food is one of the key drivers of resource redistribution around the globe in an agrifood context. The long-term sustainability of systems that extract soil nutrients, or cause erosion in one country, in order to provide processed food in another has to be questioned. While this book will not focus on these issues, it will address some of the tools available to evaluate them.

1.2.6 Environmental impact

For many consumers the impact of processing on the environment is not clear. Tools such as Life Cycle Assessment allow specialists to understand the interactions, and simplified outputs such as carbon footprint can be used to inform consumers. Society, and in many cases scientists are at the very early stages of understanding the real impacts (both direct, such as discharges to air, water and soil; and indirect, such as transport energy emissions) of food processing on the environment. However, as the environment is a key stakeholder in the sustainability concept (along with social, economic and productivity issues) it is clear that unwanted impacts need to

be minimised and reduced. The geographically distributed nature of modern food chains, with processing at their heart, mean that consumers are not always affected by the choices they make, but others elsewhere in the world are.

1.2.7 Eco-labelling

There are now hundreds of eco-labels in use around the world. These range from certification of the type of production (e.g. organic) through to certified origin or carbon footprint. At present few consumers seem to really understand what the labels mean and how they should be used. Retailers also seem to be struggling with how to use them, but it is clear that they are here to stay and will become a key driver of sustainability in the future. It remains to be seen how this impacts food processing.

1.3 Book objective

The overarching objective of this book on Sustainable Food Processing is to provide information to scientists and the industry that will assist in understanding and finding ways of increasing sustainability in the food industry, particularly that part focused on added value processing. Future developments must ensure more efficient food production, processing and distribution alongside responsible consumption to limit intake to 'fair share', to reduce waste and to mitigate future environmental and socio-economic concerns. With the estimated increase in food supply needing to rise by 70% by 2050 there will be more innovations in primary agriculture, food processing, supply chain infrastructure, public health and education. The focus has to be on meeting the demands of the present by not undermining our ability to produce more in the future. This requires attention to the current adverse environmental, social and economic impacts of food production, processing and supply through the exploitation of science and technology and a recognition that food processing, while founded in science, technology and engineering, has an impact on the environment and on society.

1.4 Book structure

The book is divided into four sections. Section One deals with principles and assessment of sustainability in the context of food processing, Section Two summarizes sustainability in various food processing applications within the food industry, Section Three considers sustainability in food manufacturing operations that are vital in food production systems and finally Section Four addresses sustainable food distribution and consumption.

1.4.1 Section One: Principles and assessment of sustainability

The concepts of sustainability, life cycle assessment and risk assessment in the food chain are approached from a food production system perspective. Sustainability is a complex concept, which involves judicious use of various resources as discussed in Chapter 2. Use of both renewable and non-renewable resources in food production systems has resulted in various environmental issues. Their impact on the sustainability of various food processing industries is dealt with in Chapter 3. Ensuring sustainability in food production systems requires a holistic approach to assess the impacts of a food product, process or service. Chapter 4 emphasizes the theoretical basis for Life Cycle Assessment in food production systems with specific examples from the food industry. Environmental impact assessment of food processing operations to produce food for an increasing world population without causing depletion of natural resources and severe pollution problems is highlighted in Chapter 5. Risk analysis in a food chain to reduce food related health issues along the entire food chain, and to ensure sustainability in food production, processing and consumption is covered in Chapter 6.

1.4.2 Sustainability and food processing applications

Application of sustainability concepts in various food processing sectors are detailed for various food processing operations used in the manufacture of a range of food products in terms of environmental issues and consequently on traditional and current efforts for dealing with sustainability issues. The application areas considered are dairy processing (Chapter 7), meat processing (Chapter 8), seafood processing (Chapter 9), fresh-cut fruit and vegetables processing (Chapter 10), food grain processing (Chapter 11), brewing (Chapter 12) and processed food industries (Chapter 13).

1.4.3 Sustainability in manufacturing operations

Food production systems require input from various allied industries involved in food manufacturing operations. Food packaging and storage operations are necessary for delivering safe food for consumers. Environmental impacts and sustainability issues related to packaging and ways to reduce environmental impacts are discussed in Chapter 14. Cleaning and sanitation within the food industry is an important operation with a significant impact on environment. Chapter 15 deals with the issues specific to the sustainability of cleaning and sanitization. The importance of cold chain management in food facilities needs to be considered when specifying and optimising sustainable food refrigeration systems and the need for effective cold management as discussed in

Chapter 16. Consumption of water and energy in the food processing sector is important. The food industry needs to reduce both the water and energy consumption for food manufacturing. Analysis of energy and water consumption and various strategies to reduce their use are presented in Chapters 17 and 18. Chapter 19 is devoted to the analysis of the types of waste arising from the food supply chain, the main causes of waste generation and its fate and reduction strategies.

1.4.4 Distribution and consumption of food

Food travelling greater distances is likely to be stored in greater volumes and the usual economies of scale will apply, with carbon emissions per kg of product possibly being lower as volumes/mass increases. Chapter 20 discusses the concept of both national and international food distribution. Chapter 21 outlines the need for sustainable food supply networks and the final chapter (Chapter 22) deals with the food security and consumption. Achieving sustainability in food consumption is vital to provide a good quality of life, while reducing the environmental, economic, social and political impacts of food production and consumption.

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Section 1

Principles and Assessment

2

Current Concepts and Applied Research in Sustainable Food Processing

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2.1 Introduction

The threat of limited food security has been highlighted globally in recent years where the attributes of environmental degradation, economic growth, population increase and climate change have uniquely impacted on the world food system (Headey and Fan, 2008). This has focused intense policy activity on sustainable production, processing and manufacturing of food products. Food processing and consumption has a most important role to play in determining the environmental impacts of resource use as identified by key policy and research reports (DEFRA, 2010a). Indeed, reporting of limitations within the food system has highlighted crisis situations for governments and the populations of nations (Brown, 2009). If we are to manage food consumption sustainably it is necessary to investigate the resource flows across food supply chains where the processing and manufacturing functions have a critical role in delivering sustainable products. The role of processors and manufacturers will be critical because profitable business practices can be maintained

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by sustainably reducing resource use. This has emerged because of the embodied greenhouse gas (GHG) emissions, energy and land use associated with all manufactured food products is subject to costs, benefits and environmental impacts that are of intense policy and commercial interest (Wallén, Brandt and Wennersten, 2004). The focus on resource use has provided innovative applications in how processors and manufacturers utilize resources more efficiently and they will be described in this analysis.

Food production and consumption processes provide complex issues regarding food security and dietary quality which must be included in assessments of efficiency if sustainability criteria are realized (Godfray, Beddington, Crute, Haddad, Lawrence, Muir, Pretty, Robinson, Thomas and Toulmin, 2010). This is particularly acute for food products because of the intrinsic embodied land use attributes they have associated with their production (Burney, Davis and Lobell, 2010). Transferring the realization of these cost and benefits into a sustainability matrix, green-product rating and commercial context remains a challenge that eludes many companies who have placed ethical trading at the heart of their activities. In this analysis of current issues we will provide an insight into how companies can isolate key issues and report them to stakeholders and identify the tools required to approach an assessment of sustainability for food products. The role of processors and manufacturers in attaining sustainability criteria has stimulated the development of novel management systems. These diverge from previous systems that have been primarily focused on product volumes and production efficiencies such as Environmental Management systems (EMSs), Lean or Six Sigma. The novel methods include the footprinting methodologies for carbon and water that are becoming international standards and they will change how food products are processed and manufactured (Carbon Trust, 2006; BSI 2008; Ridoutt and Pfister, 2010). The PAS 2050 and Carbon Label systems are high profile examples offering a standardized and credible measure of resource use efficiency that are communicated to customers.

Food processors and manufacturers have a critical role in the supply chain with regard to designing products that are integrated into sustainable diets. Currently, measured sustainability criteria such as the carbon footprint are focused on the embodied energy and GHG emissions associated with individual products. However, whole meals and population diet sustainability criteria are largely unknown and untested. We consider how the delivery of sustainable diets presents future opportunities to processors and manufacturers. This is because product development innovations can focus on the delivery of whole meals and the associated GHG, water and waste impacts associated with diet where they have previously focused on individual products not meals. Indeed, this presents a novel approach that many processors and manufacturers have not fully considered yet even though the food industry has developed meal-guides, recipes and recipe literature associated with specific products that are established with regard to delivering nutritional goals for consumers. However,

sustainable goals or impacts or food for consumers are not generally promoted in dietary guides and literature. This results in sustainability being perceived as an interesting but immeasurable consumption goal for many organizations and individuals. It does not have to be like this because the industry has the tools and skills that have been applied to improving nutritional communications that can provide a model for promotion of sustainability.

This analysis provides the caveat that if consumers could measure and respond to the sustainability value of whole meals and their diet then they would potentially change how they purchase and consume products for sustainable outcomes. Indeed, we suggest that the future consumer will hold both nutrition and sustainability criteria of foods with equal value. This will mean that processors and manufacturers will have to design products for diets that are nutritionally robust and result in lower GHG emissions, water use and waste production. A further complexity of the food sustainability goal is the impact of continued global population growth and cultural transitions. The United Nations population projections and the UN Food and Agricultural Organization food production and consumption trends provide a means to develop an assessment regarding the question of how much food needs to be produced in the next 40 years. Research presented by Keating and Carberry (2010); provides scenarios based on low and medium world population projections of 8.0–9.0 billion in 2050 (United Nations, 1999; 2009). They have assumed human fertility trends and consumption remain constant based on previous population data. The scenarios show the world will need to produce over 380 to over 400 exa-calories (1 exa calorie $= 10^{18}$ calories) over the period 2000 to 2050 if an average consumption of 2255 kcal/person/day is maintained. This is equivalent to the food the world has produced over the 200 years pre-2000 in order to feed its population. A further scenario presented by Keating and Carberry (2010); assumed a mean global consumption of 3590 kcal/person/day by 2050 is reached. This might be considered more realistic if current trends continue and the resulting demand will be for over 450 exa-calories which is the equivalent to the food produced in 330 years pre-2000. These scenarios provide an assessment of the challenge that faces food supply over the next 30 years. In reality we will have to produce food at an efficiency which is up to ten-fold greater than we are currently doing.

The food security implications of population projections become even more profound when we relate them to the consumption of protein. This is because 65% of global protein consumption is from just seven major food ingredients as reported by the FAO. These are wheat (20%), rice (12%), maize (5%), dairy (10%), beef (6%), poultry (6%) and pork (6%). Furthermore, livestock product consumption provides specific stressors on the global food system because feed protein is consumed by livestock to produce meat as a protein source at conversion efficiencies that range from 5% for beef products to 40% for dairy products (Smil, 2002). The nutrient transition of the world food system to more meat containing diets has resulted in an increased demand for

meat creating a dilemma for sustainability of resource use because of the demand for feed protein. This can be demonstrated using current world production of cattle, poultry and pig livestock for food which requires 1.2 billion hectares of wheat-equivalents if we use the protein conversion figures of Smil (2002). Considering that there are 0.5 billion hectares of arable land globally the demand for livestock feed will create increasing pressures on the demand for feed protein and the food system. Previously, interventions to supplement feed protein have focused on improving grazing systems so that the 3 billion hectares of permanent pasture available globally can efficiently achieve this and reduce demand for cereal feeds. However, in this analysis we highlight the increasing importance of processors and manufacturers in providing a means to ameliorate pressure on the meat consumption system by the utilization of all co-product and waste streams for protein supply. Furthermore, the growing importance of using industrially produced protein converted from starch at much higher efficiencies than livestock systems is investigated.

This analysis will highlight the two following issues that we feel are of greatest importance in the development of a sustainable food system. Processors and manufacturers will provide the skills and innovation to deliver lower impact products that ultimately provide nutritional well-being. They are as follows:

1. The provision of product ranges that are accredited for sustainable criteria such as lower GHG emissions. These products will provide a basis for sustainable meal and diet planning for populations. This will require changes to current processing and manufacturing practices. The delivery of sustainable diet by processors and manufacturers will also require communicating to consumers and new marketing tools will advise and add value to existing nutritional consumer tools.
2. The delivery of sufficient protein for human well-being is a human right and the food processing and manufacturing industry offers many opportunities for providing efficient feed protein to edible livestock protein, and, starch to protein conversions. The processing industry is of huge importance in optimizing protein consumption through the design of recipes, meals and products so that consumer well-being is enhanced and environmental impacts are reduced.

The requirement for green-product ratings is established and in the food processing and manufacturing arena energy-use must be a focus (Keegan, 2011). Furthermore, relating product development to whole meals and diets is critical and this requires a full appraisal of whole supply chain activities. This will mean the systems processors and manufacturers have in place to determine traceability of food ingredients and assure safety or crisis management will be critical because these systems will provide an overall knowledge of supply chain impacts. An important consideration and stressor for sustainability of food supply chain management is population growth which is further compounded by increasing urbanization and nutrient transition trends.

2.1.1 The transition from the rural producer to the future urban consumer in the 2050 world

Improving the efficiency of resource use in food processing across whole food supply chains is an essential component of getting food to more people using decreased inputs. Population scenarios provide a specific challenge to the food processing and manufacturing sectors where the emergence of methodologies that can provide greater efficiencies for the delivery of sustainable consumption targets should become standard practice. An essential component of realizing these greater efficiencies is the integration of farming, processing and manufacturing with regard to producing sustainable quality and quantity of food (Zufia Arana, 2008). The reduction of GHG emissions, water use and food waste will be essential and the integration of smarter design and logistical planning in supply chains is required to do this (Costa and Jongen 2006; Kumar, 2008; Webber and Matthews, 2008). Marketing the sustainability agenda to consumers will help to ameliorate threats to food security that are also institutional or behavioural in nature (Bánáti, 2008).

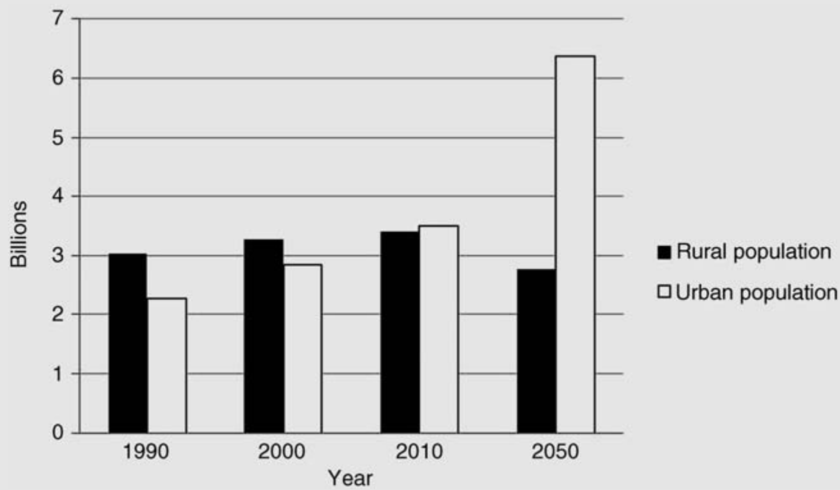
The food security issues of our current food system are very different to those faced in the twentieth century when the solutions delivered were focused on crop and food production (Smil, 1999; Trewavas, 2002). Whereas, the same agricultural production solutions are still required, there is a need to integrate sustainable food processing and manufacturing solutions with production, distribution and retailing components of food supply chains (see Section 4). Indeed, the green revolution must become even-greener.

The food security situation for a projected global population of 8–9 billion people in 2050 will demand the production of more food using even lower energy inputs within current land use limits. Nutrient and cultural transitions are changing global diets such that they are likely to contain more meat and dairy products so that production solutions alone will not deliver sustainable food security (see Box 2.1). An understanding of the whole food system and supply chains will be required by food processors and manufacturers because consumers are changing life styles, expectations and demand for specific foods (Popkin, 2001; Popkin and Siega-Riz, 2001; WHO, 2003; von Braun, 2007). This will ultimately impact on sustainability criteria.

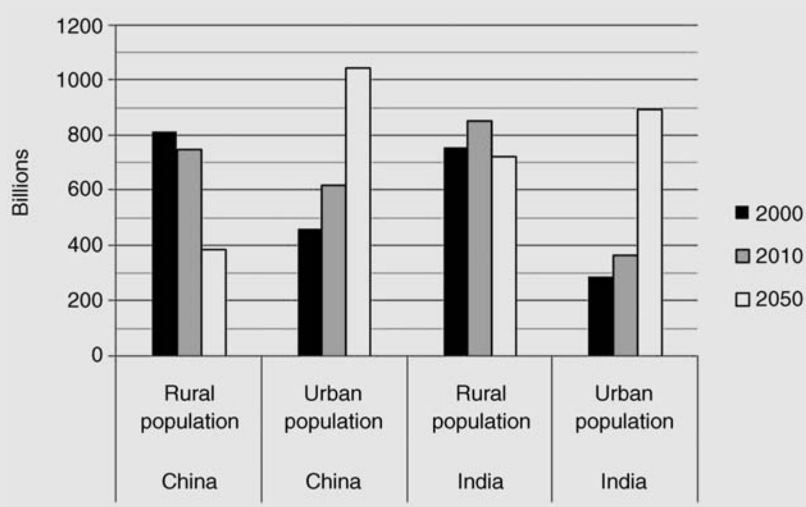
Box 2.1 World population transitions

The world population is the major driver for changes in consumption. Nations that are undergoing rapid economic development such as Brazil, Russia, India and China will experience large changes in manufactured food demand. This is most emphasized globally by the transition of populations living rurally to those living in urban environments. Urban

living will be associated with changes in how meals and diets are used and it will change choices across all supply chains. This trend is shown in the following figure from FAOstat data. The data below shows increased urbanization for the global population.



This scenario is specifically emphasized by the transition for China and India where rapid urbanization will result in dramatic changes in food demand not only in terms of volume of products but also in terms of the life style criteria associated with those products.



Processes that can link food supply to changes in dietary culture have a clear role in reducing the impact of more energy intensive foods such as meat or dairy products (Tilman, Fargione, Wolff, D'Antonio, Dobson, Howarth, Schindler, Schlesinger, Simberloff and Swackhamer, 2001; Tilman, Cassman, Matson, Naylor and Polasky, 2002; Thornton, 2010). However, austere dietary policy approaches will not work because even at a global level the cultural interface of food and tastes are increasing the demand for meat and dairy products dramatically. Consumer food choices are often in conflict with nutritional benefit and the link between health, food culture and manufacturing industries is often not integrated by food companies (Kearney, 2010).

National food agencies representative of industrial agricultural industries have used regulatory constraints that have stimulated processors and manufacturers to improve healthiness of (DEFRA, 2010a). The future food system will result in a requirement for food processors and manufacturers to consider the three principles now described.

1. The design of efficient supply chains that can deliver safe perishable foods that require efficient preservation that is currently dominated by the cool chain. A future food system must consider all preservation techniques that can extend the shelf life of products in urban retail environments including ultrasound, high pressure and irradiation treatments of food products.
2. The design of foods that provide sustainable meal planning providing high nutrition and low environment impacts is a focus for sustainable development. This will require an assessment of portion size and fit-for-purpose packaging so that consumers can use the appropriate amounts of food for meals and produce less domestic food waste.
3. Aligning processing and manufacturing practices with policy guidance is critical for regulatory compliance. However, the food processing and manufacturing industries hold an importance supply chain position where data sets required for footprinting products are routinely collected but not fully utilized. This provides an opportunity to lead and develop food and consumer policy in the future food system.

2.1.2 Strategic approaches by food companies to the food sustainability policy challenges

The integration of regulatory measures and policy making has stimulated food manufacturing and processing companies all over the world to develop sustainability strategies that have specific focus on issues related to energy, water, waste management and the environment (for example see, Unilever, 2010). These plans are driven by social, legislative, economic and political

issues that will result in food products being made with lower energy, carbon and water footprints. These strategies focus on the following criteria:

1. The cost of energy and water is rising and water will become scarce and vary in availability because of climate change (Wright, Osman and Ashworth, 2009; Woods, Williams, Hughes, Black and Murphy, 2010).
2. Legislative and financial issues may restrict water use and impose restrictions on the amount of greenhouse gases a product can embody in a carbon footprint. There is also likely to be tougher legislation and/or financial costs on effluent discharges and waste generation and all food sectors will need to be prepared to manage change (World Wildlife Fund and Food and Climate Research Network, 2009; World Wildlife Fund, 2010).
3. Choice editing that is, limiting the food choices available to consumers will be imposed on the food industry by retailers and consumers for producing products that are environmentally friendly with low carbon and water footprints. Therefore, understanding how to robustly communicate processing operations to consumers is crucial to business success (Bredahl, Northen, Boecker, Normile, 2001).
4. Companies will become more aware of their social and human rights responsibilities to their customers and the environment, and they are likely to implement 'fairer', 'greener' and 'leaner' approaches in their manufacturing operations. This is already an important issue, with many visionary companies endorsing policies on sustainability and integrating them into their mission statements (DEFRA, 2007; DEFRA, 2008).
5. Sustainable food manufacturing has been proven to have a positive impact on the profitability of these visionary companies (Price Waterhouse Coopers, 2010).

Furthermore, consumer demand for sustainability criteria has increased even though most purchase decisions are clearly focused on price and quality criteria of products (DEFRA, 2007). An apparent opportunity for the food manufacturing and processing sector is the increased awareness of meeting energy use targets through national reporting and trading schemes that aim to decrease greenhouse gas emissions. Energy consumption reporting is critical within the food processing and manufacturing sector because energy inputs are intensive for generation of steam, hot water and heat. The emergence of markets that support greenhouse gas emission reduction has provided sector leadership and the opportunity for companies to differentiate their products based on sustainability criteria associated with supply chains.

An important aspect of developing sustainable foods is the engagement of external and internal stakeholders for the food supply chain (DEFRA, 2008). The issues that arise from the stakeholder engagement process are effectively reviewed by policy making instruments and the United Kingdom

Government's current food plan, the Food 2030 Report summarizes many of these issues.

The UK's Food Plan, Food 2030, has been developed from previous reports that include the notable Food Industry Sustainability Strategy (FISS) and the cross UK government report, Food Matters (DEFRA, 2006 and DEFRA, 2009). The FISS and Food Matters provided a comprehensive analysis of the UK food system covering issues from farm to consumer. Food Matters implemented actions that have been reported and are now embodied in the Food 2030 report representing the UK's national food plan (DEFRA, 2010). The Food 2030 Strategy is structured around six core issues for the future food system. These are as follows:

- encouraging people to eat a healthy, sustainable diet;
- ensuring a resilient, profitable and competitive food system;
- increasing food production sustainably;
- reducing the food system's greenhouse gas emissions;
- reducing, reusing and reprocessing waste;
- increasing the impact of skills, knowledge, research and technology.

The implementation of Food 2030 Strategy is presented by a 'who, what, how and result' approach with stakeholders and this is relevant to the food manufacturing and processing sectors. The implementation guidelines have included all stakeholders in the food system including academic, industrial, policy, governmental, consumer and voluntary organizations as the 'who' to implement specific parts of the Food 2030 Strategy. The comprehensive issues identified for obtaining a sustainable food system in the FISS, Food Matters and Food 2030 deliberately tackle how implementation will occur. This represents a novel approach in food policy and it has gained considerable momentum amongst food manufacturers and processors who are aligning their businesses with the themes presented.

A further relevant policy document published in the UK is the Future of Food and Farming Foresight study by the UK Government's Department of Business Innovation and Skills (2011). This Foresight report clearly integrates the requirement for food security and environmental quality in a future food system. An important aspect of the use of resources highlighted in the Foresight report is the need to maintain ecosystem resilience in food production systems. The approach is to consider the ecosystem services embodied or associated with the production and consumption of food products. Ecosystem services include attributes that represent benefits provide by production including GHG emission abatement, enhancing biodiversity, improving water resource use amongst others (Costanza, d'Arge, de Groot, Farber, Grasso, Hannon, Limburg, Naeem, O'Neil, Paruelo, Raskin, Sutton and van den Belt, 1997). The ability to measure the value of ecosystem services associated with food products is likely to be a focus of future developments in manufacturing

that align with consumer demand for conservation and responsible land use (Smith, Gregory, van Vuuren, Obersteiner, Havlík, Rounsevell, Woods, Stehfest and Bellarby, 2010). This is because all food production impacts on land use change directly (land use) or indirectly (land use impacts outside of the food system) and these criteria will be embodied in all food products. A means to reduce land use associated with food products is the consideration of lower meat diets and the food manufacturing and processing sectors are providing innovative products that will help to achieve this.

For example, an initial LCA of the mycoprotein and Quorn™ production has been reported by Finnigan T (Quorn Foods Ltd), Lemon M, Allan B and Paton I (Institute of Energy and Sustainable Development De Montfort University UK) in an LCA carried out for Premier Foods plc. The data demonstrate that the direct CO_2e of both mycoprotein and Quorn™ product production, and that of two key raw materials, eggs required for the albumen and glucose, contribute most to the production of CO_2e and therefore the Global Warming Potential (GWP) of the process. From the current data, estimates suggest that tonnes of CO_2 equivalents released per tonne of product (ending at the storage of the products prior to distribution and consumption) are: 14.3t CO_2e per tonne of beef; 6.8t CO_2e per tonne of Quorn™ mince. This can be reduced to 5.6t CO_2e if steam production is not included as the steam used is a waste product from a separate manufacturing process. For Quorn™ mince, the production of mycoprotein contributes to 3.1t CO_2e and the rest is generated from the processing of the mycoprotein into Quorn™ products. These initial estimations suggest that Quorn™ mince may have a significantly lower CO_2 emission than the production of beef.

Life Cycle Analysis (LCA) methodologies provide a means to assess the potential trade offs in choosing different food products for a balanced diet. Traceability systems need to be in place so that green product ratings can be extended to brand, meal and diet scenarios. Meat consumption and protein balance provide specific issues for the food industry that will be addressed more critically in the future business arena. An assessment of the impact of protein production will ultimately be reported on the basis of ecosystem service approaches.

A strategy for measuring all the environmental impacts of food processing from harvest to shopper within a company is a prerequisite for delivering sustainability within the food system for manufacturers and processors. It is clear that in considering the food manufacturing and processing environment we must consider the whole food supply chain and ultimately the whole food system in order to obtain a robust view of how sustainable it is. The six core themes of the Food 2030 report and those of other national food plan delivery models are of significant relevance to food manufacturing companies because they identify the goals of current policy over a 20-year time frame. How companies implement processes that align manufacturing and processing to day to day operations in food manufacturing and processing environments and

are able to account for sustainability will be critical to delivery of consumer requirements.

Thus, companies must integrate current policy initiatives into process and manufacturing design and the following four principles will guide many future activities that deliver sustainability and drive future policy:

1. The provision of food that has been responsibly produced and considered ethical by the consumer will be increasingly important. Fair Trade food products while representing a small share of the food system with £1.6 billion (UK Sterling) in sales they are experiencing dramatic growth for specific products such as banannas, coffee and chocolate (Fair Trade Foundation reported figures). Livestock products that are certified with animal welfare accreditations are also experiencing significant growth in sales. These trends have implications for sourcing ingredients and assuring the traceability of those ingredients.
2. The development of food supply chain traceability systems is essential to future development of the future sustainable food system. Traceability is required to obtain data for environmental footprinting, safety and ethical credentials.
3. Companies that ensure the fairness of their products are in a stronger position to add value and respond to consumers who will preferentially buy assured products.
4. Companies can develop Corporate Social Responsibility systems that align their business operations with policy guidance and use traceability data to define the social responsibility associated with products. Responsibility will not only include lowering environmental impacts but also consider human rights, welfare and nutritional outcomes. Responsibility associated with nutrition is a current policy focus because of the rising levels of obesity in developed and developing nations.

2.2 Sustainable procurement

Specific product LCA approaches can address a growing need to understand wider impacts that relate GHG emissions to water use, land use, biodiversity impacts and other attributes. However, this can lead to trade-off situations that must be defined by companies who are required to report impacts in order to comply with investor and shareholder directions. Methods of evaluating the GHG emissions associated with the production of food and beverage products have been implemented in response to current policy goals that aim to reduce GHG emissions (BSI, 2008). They have in turn stimulated New Product Development (NPD) in the food and beverage sector.

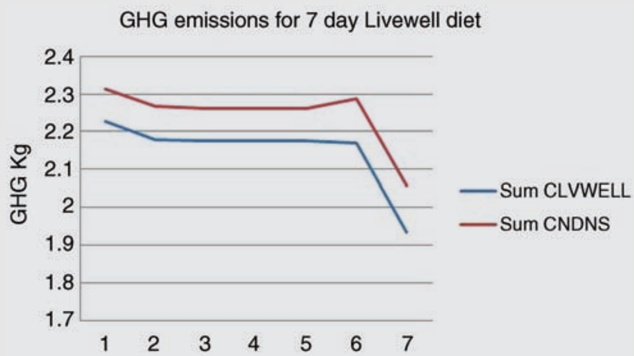
The drivers for integrating sustainable food processing and LCA approaches into food business goals and supply chains include the following:

- Development of methodologies for measuring efficient sustainable food processing.
- Development of scientific communication strategies for consumer communications and behavioural change for changes in demand of food products.
- Integration of scientific research with market-based strategies.
- Development of transport, seasonal and local food and beverage strategies.
- Integration issues related to sustainable food processing and health and well-being.

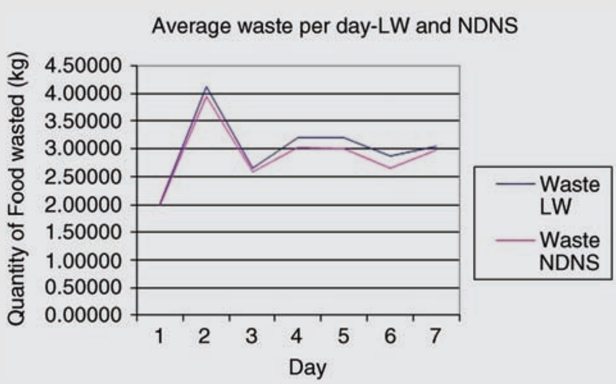
The complexity of delivering safe and sustainable food is determined by the large volumes involved. The European food system serves 480 million people each day with food and drink (Raspor, Mckenna and de Vries, 2007). Furthermore, it is clear that the current food needs of consumers in developed nations are becoming more complex than just volume and price determined. This is because considerations of environmental impact, social responsibility, functional foods, nutraceuticals, obesity and food miles are driving the emergence of new products (UK Cabinet Office Strategy Unit, 2008). The food processor and manufacturer can enhance these values even though there is a requirement for low price, product variety and increased choice (Costa and Jongen, 2006). In turn, the food manufacturing requirement for the application of innovations is often driven by both consumer (shoppers, retailers, food service providers) and regulatory pressure (DEFRA, 2007; DEFRA, 2008). Applying LCA approaches to higher levels of populations and their diet is a challenge for the future of the food processing and manufacturing sectors. There are initial studies that deliver these food system level approaches for LCA of food and whole diet (see Box 2.2). These are critical future requirements for food companies who will have a need to equate life style with sustainability. The approach is not completely novel because the food industry works with brands and has labelled products based on health criteria. A future development to extend these attributes to sustainability criteria is necessary and possible.

Box 2.2 Sustainability as part of consumers' diets

The World Wildlife Fund has developed the Livewell Diet with the Rowett Institute, Scotland. The diet is based on sustainable criteria and the graph below shows the 7 day diet has a reduced carbon footprint based on data derived from Wallén, Brandt and Wennersten (2004). The reduction in carbon footprint as compared to the current diet in the United Kingdom reported by the National Diet and Nutrition Survey is between 5–10% per person per day (unpublished data, W. Martindale and K. Lucas 2010). These represent small life style changes that processors and manufacturers can stimulate using portion and product design options.



However, initial research at the Sheffield Business School shows the waste food generated from more sustainable diets is greater than current food waste. These scenarios place important considerations on planning for sustainability. It is critical that sustainability planning by the processing and manufacturing sectors is integrated with changes in the way in which consumers utilize and dispose of food. This again represents opportunities for processors to consider the value of preservation and freezing options to enhance the sustainability criteria of food products.



The process of benchmarking sustainability criteria across food supply chains and populations will provide applications for food processors and manufacturers because it is clear that the sustainability of a supply chain cannot be assessed by carbon equivalent emissions, water use or waste production alone. A far broader assessment of sustainability is required that relates social responsibility, carbon, water and waste to the consumption behaviour of individuals and populations. Many farm and food assurance

schemes attempt to consolidate sustainability criteria for products but there are still significant opportunities to assess and communicate sustainability criteria for individuals and benchmark these to typical population trends.

An essential aspect of responsibility across food supply chains is auditing procedures such as Global GAP (see Global GAP, 2011) should not penalize or marginalize producers who are provided with resources to implement assurance schemes so that equitable and fair solutions are obtained. Currently, social impacts and biodiversity impacts associated with food products have lower visibility than carbon, energy, water and waste representing an opportunity for the research community to respond to support the further development of sustainable food supply.

2.2.1 The interface between nutritional and sustainability criteria

The development of new products that target the healthiness and well-being markets has increased significantly since the 1990s when the UK Government's Foresight group for food and non-food crops supply chain management identified health as being a major factor in the future food industry. However, the link to whole meals was not robustly made and left to recipe publications and popularization of culinary skills and food preparation. This scant attention to whole meals and diets by the processing and manufacturing industry will not provide sustainable outcomes for food supply and needs to change. There have been significant areas of recipe development that have impacted on the food manufacturing and processing sectors. For example, traditional recipe planning used by manufacturers in New Product Development (NPD) has made use of cheaper ingredients such as fat and salt to reduce the unit cost of product. However, health policy developments such as the UK Food Standards Agency 'Five-a-Day' programme have changed the approach of many manufacturers to NPD. Commercial and Government-led policy pressures have led to an increase in the utilization of vegetables for 'bulking-out' (cost reduction), attainment of product marketing claims based upon the 'Five a Day' initiative, and, a decrease in the salt content of recipes (FSA, 2007). Consumers and retailers are more label-aware with the emergence of clean label issues (UK Cabinet Office Strategy Unit, 2008). This activity has been extended to the food service sector with the School Food Trust (2007) enforcing regulatory actions that define nutritional standards in schools. Although the food service sector shopper rarely sees the ingredient declarations stated upon the product label it is a sector where ingredient planning is an intense activity. Nutritional quality, traceability and provenance are increasingly important to consumers in food service environments and regulatory activity is likely to be extended in future food service markets.

The reduction of salt has been an area of much process innovation even though the impetus for salt reduction has been guided by regulators raising the issue of who drives the requirement for changes in recipes so that they align with healthier outcomes. The Food Standards Agency emphasized the requirement to reduce salt consumption to 6 grams of salt or 2.40 grams of sodium per adult per day. DEFRA has reported that in 2008 sodium intake, excluding table salt and allowing 10% for wastage, was estimated to be an average of 2.78 g/person/day from household purchases plus food eaten outside the home. This is a reduction of 2.2% on 2007 and a 14% decrease since 2001–2002. Thus the food manufacturing and processing sector has responded to a national health indicator (CIAA, 2007). This is emphasized by the use of unami flavours that were derived from seaweed or yeast products as alternative flavour enhancers that have provided innovative product formulation in the food processing sectors. These scenarios need to be integrated into whole meals for sustainable health outcomes.

2.2.2 The relevance of consumer science to sustainable food processing

Consumer behaviour represents a distinct gap in our understanding of how consumers interact with foods and data on the experience of taste and satiety are an essential part of developing new products and how they are manufactured (Breslin and Spector, 2008). Flavour and fragrance composition is recognized as a highly complex and technical aspect of formulating foods, but our understanding of how satiety is controlled will impact on how we manage the planning of resulting food product design for sustainable processing. This is an area where nanotechnology is providing new understanding of encapsulation and delivery of nutrients in the body (Graveland-Bikker and de Kruifa, 2006). Understanding consumer experience of taste will provide insights into how nutrition and satiety interacts with consumption (Slimania, Deharveng, Unwin, Vignat, Skeie, Salvini, Møller, Ireland, Becker and Southgate, 2007). The food industry can respond with novel approaches of formulating products, as an example the use of optimized micronutrient content in foods is as a potential means to reduce consumption of energy dense and nutritionally poor foods that enhance appetite and over-eating (Ames, 2011). The opportunities for understanding taste, satiety and consumer behaviour should be considered together with those of materials and the texture of foods by processors for innovative outcomes.

Food 2030 suggests a need to reduce our consumption of meat because of its impact on health and the environment. Mycoprotein developed in the 1960s from the *Fusarium* fungi provides a means to convert starch to protein by fermentation. This process provides opportunities that were initially

developed to tackle a population protein supply limitation in 1965 under the direction of Lord Rank.

The protein is grown in batch air-lift fermenters and harvested. The mycoprotein paste undergoes an innovative and intensive series of steaming, forming and chilling processes in order to produce a range of vegetarian products that comprise a meat-like, novel texture along with proven nutritional benefits of low fat and cholesterol and potential satiety benefits. The products are branded as Quorn™ and include fish and meat free products fortified with omega fatty acids from algal sources. The branching microstructure of mycoprotein offers a potential texture difference to the linear structures of other meat free proteins and this contributes to Quorn™ product success. The rheology of mycoprotein and the versatility of products offered are constantly assessed by sensory panel testing and benchmarking of products against other brands in the marketplace. The data from such studies is developed with the processing operations to provide food products and structures that provide healthy options, new tastes and textures.

There are also likely to be sustainability benefits to utilizing meat free proteins that are industrially produced because manufacturing and processing will utilize less embodied land use and reduce GHG emissions. These criteria are currently being considered with regard to products across the food industry for further development of Corporate Social Responsibility (CSR) strategies.

An illustration of how global tastes are changing is shown on a macroscale by the increased production of crop commodities associated with taste as compared to food staples (see Table 2.1). Food staples have remained relatively constant in these terms with palm oil production providing an exception where production increased globally by nearly three-fold between 1990 and 2009.

Global food production statistics suggest a dramatic change in the requirement for products that improve flavour and taste. Identifying these trends is important to business planning for food processors and manufacturers.

Table 2.1 Trends in production for selected agricultural products obtained from FAOSTAT (2011) data that provide key ingredients in the food production system

	Production (Mt)		
Crop	1990	2009	Increase (ratio)
Spinach	4.087	19.611	3.798
Garlic	6.600	22.282	2.376
Chillies	12.845	31.209	1.430
Sugar crops	1363.207	1889.307	0.386
Wheat	592.372	685.614	0.157

Nutrient transition is beginning to create sensational outcomes, for the first time global urban populations outnumber rural populations and the impact of the ‘Brazil, Russia, China, India- or BRIC’ nations is being felt on the global food system.

2.2.3 Communication programmes for healthy diets and their relevance to processors

There is a need to define what a healthy diet is for consumers who have significant interest in the development of balanced diet. The balance of nutrients should be a basis for healthy diet that will stimulate future food product development and processing. Sustainable diets are an area where consumers have a ‘notion’ of what to expect and drivers to improve the healthiness of food products have undergone dramatic transformation. The food industry has responded clearly by changing labelling, lowering salt content and using ingredients that provide significant health benefits. This has revolutionized many aspects of NPD and reformulation: However, the application of these associated datasets are rarely applied to whole meals or diets and how consumers use them. These are important developments because they relate products to diets and wider food supply issues such as recipe and food use in populations that clearly align with sustainable outcomes.

2.3 Sustainable food supply management

The global food system operates in a robust regulatory system that ensures safety of products but this should not stifle innovation and the application of new technologies. Innovative technologies can be applied to enhance nutritional quality of food using novel ingredients, nano-encapsulation of nutrients, biofortification and nutrient profiling.

Resilience in the food system is identified as a sustainable goal by many policy makers and the manufacturing and processing sectors have an important role to deliver with regard to resource use.

The requirement for LCA methods and sustainability audits has developed because the limits of regional food product supply have been traditionally ameliorated by efficient food logistical infrastructure, preservation and packaging. We are now beginning to account for these limits. Indeed, they are driving the development of much innovation and regulation in the industry. Supply chain resource efficiency, managing natural resources, accounting for energy, water and waste will become more critical to the success of the sustainable business model. However, integration of production and manufacturing processes with respect to sustainability criteria are largely unexplored by many food companies because purchasing strategies have been

based on price, perceived consumer quality and volume. There are already requirements for this integration in supply chains to occur because the health attributes of food products can be influenced by agricultural production methods.

2.3.1 Food processing and the carbon footprint

Reduction of greenhouse gas (GHG) emissions represents a goal that packages many sustainability criteria for most food manufacturing and processing companies. Energy optimization in the food system is critical to future sustainable development. If we consider indicators of sustainability, energy consumption by companies is potentially most useful for identifying where improvements can be made. Energy balance approaches could have important uses in the future development of food policy and public communications. For example, the energy consumed in the UK food supply chain is 6% of national energy consumption and an important consideration is the structure of how the energy is used by the UK food supply system. The UK scenario will be typical of many industrial food supply chains with up to a quarter of the 160 Mt CO_2e p.a UK GHG emissions of the food system associated with cold preservation of food (from the DEFRA Food Statistics Pocketbook, 2010). If good practice were achieved across supply chains it would represent a significant benefit to reduce this. Furthermore, GHG emissions associated with the domestic consumption of food are 20 Mt CO_2e p.a in the UK and half of these are associated with cold preservation. This impact demonstrates huge potential in consumer energy conservation opportunities that might be offered by the industry developing new product and portion design for frozen foods. The statistics available suggest there are management, practice and design opportunities for the frozen food sector that need to be robustly identified. The importance to the business bottom-line is clearly energy and fuel conservation.

What is evident from UK data is that farming and domestic use of food account for over 50% of energy consumption in the food system. This structure of the food system is likely to be similar for many nations with efficient post harvest supply chains, advanced domestic food preservation and diverse ranges of food products. In order to implement innovative changes in energy consumption by food supply chains a clearer understanding of how energy is used in the farming and domestic environment is required so that these can be integrated with processing and manufacturing sectors for efficiency gains. Energy balance for the farming system has been well characterized (Küsters, 1999; Hülsbergen and Kalk, 2001; Biermann, Rathke, Hülsbergen and Diepenbrock, 1999) but less so for livestock systems because they are more complex, variable and the feed to carcass conversion is an extrapolation that does not consider land use but it is the

basis for analysis (Smil, 2002). An important aspect of future work is to develop a greater understanding of energy and land use in livestock production systems because research identifies higher GHG emissions are associated with high-meat diets. A robust methodology for accounting for energy used in the production of livestock products is likely to be an increasingly important need for the meat sector as identified by 'roadmaps' reported by the English Beef and Lamb Executive (EBLEX) in the UK (EBLEX, 2010). They clearly identify agronomic and husbandry factors as targets for lowering GHG emissions such as improving stock fertility, the management of grazing and feed reformulation.

There is also a requirement to develop our understanding of energy use associated with food preparation and consumption in the domestic environment. Energy management in companies is usually responsive to short term events and not embedded in business culture because of the variability in economic cost of utilities and the requirement to maintain manufacturing plant. A more robust approach to managing energy use throughout supply chains will enable a focus on lower energy use and less environmental impact from the manufacturing and processing sectors.

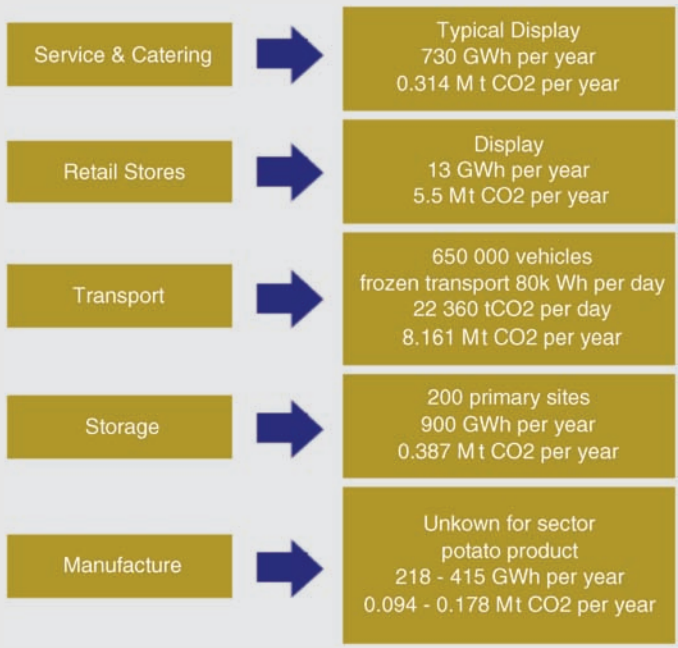
A recent report by the British Frozen Food Federation has identified that energy inputs of manufacturing are rarely recorded or corrective action in response to data is not carried out within a defined management system. The capture of consumption data for energy and waste becomes more variable the closer products are to consumers and little is known of how resources are used domestically. The study presented in Box 2.3, does not include consumer use of cold preservation and the cost-benefits of utilizing imported food to supply seasonal consumption. For example, the GHG emission associated with importing Kenyan green beans sold as fresh in the UK are double those of UK grown and frozen green beans. The issues associated with these trade-offs are complex with regard to social responsibility and require further investigation at a whole frozen food supply chain level. These are considerations that will be aligned to support the management process to optimize freezing and a potential change in frozen storage temperature for food products.

Further evidence supporting the requirement to understand how energy use is managed in the whole food system is provided by a LCA of the Swedish food supply system by Wallén, Brandt and Wennersten (2004). The data reported in this 2004 paper has been presented in Box 2.4 in terms of the relationship between the carbon footprint and embodied energy of delivering food products to consumers. There is a linear relationship between embodied energy of food products and their carbon footprint. The relationship clearly shows embodied energy is of importance to understanding how food companies and their customers use products.

Food waste minimization across food supply chains is identified by many policy makers as an area where many opportunities for reducing

Box 2.3 A refrigeration carbon and energy inventory for the UK food system

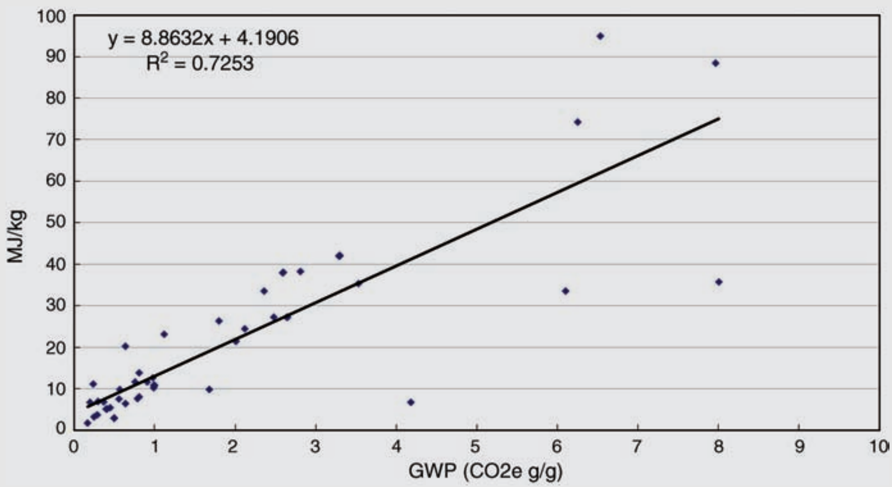
Using the Carbon Trust refrigeration road map data an energy balance of the frozen food supply chain identified transport and retail sectors account for 64% of GHG emissions (British Frozen Food Federation, 2010).



environmental impact exist. The implementation of waste minimization using ’no or low’ technology interventions are proven across industry and formalized waste management planning has become a standard protocol in many companies. Provision of efficient mechanisms for waste management technologies should be appropriate for how consumers use products. The impetus for embedding waste management in food processing and manufacturing environments has been encouraged by the economic benefits of reducing waste. Financial and tax-related instruments that have facilitated the reduction of waste and include the landfill credit and allowance schemes in the UK that is dependent on the type of waste and volume. The instruments have been stimulated and supported by European Directives and Government regulations resulting in a systemic change in how waste is

Box 2.4 The embodied energy of food products and their carbon footprint

These data are derived from Wallén, Brandt and Wennersten (2004), using the Swedish food supply chain, plotting energy inputs and GWP provides a linear response, plotting calories at consumption and GWP provides no relationship. Such analyses raise the question of using energy balances of whole food systems and supply chains to apply energy management initiatives in processing and manufacturing environments.



perceived. The food processing and manufacturing industry has specific challenges because large volumes of waste are organic and biodegradable. The establishment of anaerobic digestion, composting, pyrolysis and incineration technologies associated with solid food waste supply are now commercially proven.

Slurry and effluent wastes are an important aspect of food manufacture where large volumes of waste water with high biological oxygen demand are often produced. There are significant opportunities for non-chemical water treatment technologies such as reverse osmosis, filtration, ultraviolet, ozonation and ultrasound in the food manufacturing sector. Thus, physical treatments are gaining significant industry interest in a future where consumers are a more ware of 'clean label' products. There is also a business requirement to divert 'waste' streams to valuable co-products. Such actions generate new ideas, increased wealth and continued regulatory compliance.

Co-product markets are proven with many of the supporting technologies coming from the ingredients industry. They include starch by-products, biofuels, fibres, novel oils, waxes, cellulosics and a range of fine chemicals from biorefinery systems.

Significant studies identify that at least 20% of food purchases are not consumed and they are disposed of (Tscharntke et al., 2012). Reducing consumer food waste will have important implications for the processing, manufacturing and retail sectors with regard to product pricing and design. The food industry will need to accommodate significant challenges regarding pricing, marketing, design and portion control of products that necessitates a whole food system approach. An opportunity for reducing consumer food waste is to consider the role of preservation techniques in the supply chain with longer term preservation methods such as freezing, high pressure treatment and irradiation. Longer term methods of preservation such as freezing will need to ensure nutritional, taste and organoleptic properties of foods are not compromised and this is a focus of future innovative food research.

2.3.2 Food processing and water resources

The requirement of the food supply chain for water is greatest where water-scarcity is most intense globally. Researchers are developing methods that measure water use by food products. There is a requirement to understand how water resources are used in a system and methodologies that can measure the water footprint of processes associated with food. The water footprint measurement is achieved by identifying rechargeable and non-rechargeable water resources that are associated with food products. The method of calculating the water footprint as solely embodied water are flawed because it only refers to the total volume of the water used in the product life cycle and does not take into account the type of water used. Furthermore, embodied water footprints do not consider if the water comes from water stressed or water sufficient areas. Thus, the impact in an area where there is an abundance of water is very different to a water stressed area. Ridoutt and Pfister (2010) have provided a revised method of calculating the water footprint of a product by taking into account the Water Stress Indicator of the area where the water is used. This correction gives a much better result for the environmental impact of making that product and represents a system wide approach that depends on geospatial data. A future challenge for the water footprint methodologies is the use of spatial information that quantifies and identifies where different types of water resource exist. The implications for the management of water resources are complex and difficult to resolve because private companies, public organizations, government organizations and consumers have different commercial and

social investments associated with it. Spatial information for water resources is likely to become more valued and strategic. Research has already demonstrated that the geo-spatial information associated with food brands, food manufacturing processes and production of waste can radically change the way food manufacturers use water.

2.4 Concluding observations

The methodologies used to deliver sustainable food processing can focus on specific aspects of product design such as the established accreditations for carbon and water. However, there are emerging requirements to map the impacts of products across supply chains and populations of consumers. This approach enables a more detailed investigation of consumption to be completed for the life cycle of a product. The development of robust evidence databases for resource efficiency has enabled a greater understanding of products and their consumption. This is particularly important when accounting for the environmental impacts of diet which represent a specific challenge to the food processing industry because the footprinting of individual products may not correlate to the footprint of whole diets. Understanding how individual products are used and consumed will provide significant opportunities for the processing and manufacturing parts of food supply chains.

The value of new technologies in terms of sustainability criteria and outcomes is an area that has not been promoted by the food processing and manufacturing sectors. The opportunity is to integrate the reporting of current efficiencies to sustainability criteria such as GHG emissions, energy use and water use. Linking new technological applications and sustainability criteria will be crucial for communicating with shareholders and consumers. Data capture regarding the performance of processes in manufacturing will be critical in achieving this integrated approach and communication in supply chains.

An assessment of the drivers of change will be critical for forecasting the relevance of future sustainability research. Understanding of drivers from an international perspective will be relevant to food businesses. Specific drivers include the approach of the specific retailers undertaking carbon labelling, the impact of UK Carbon Reduction Commitment (CRC) and other emissions trading instruments used to engage industry for the purpose of GHG emission reduction measures.

These place an economic price on carbon dioxide equivalents of £12 sterling per tonne, providing strong commercial criteria for carbon reduction in business. These types of schemes have an important role in the uptake of carbon reduction methods by business. Services and products are associated with wider sustainability criteria and the delivery of wider sustainability assessment for business will grow in the future.

UK Carbon Reduction Commitment (CRC)

The CRC is a mandatory scheme aimed at improving energy efficiency and cutting emissions in large public and private sector organizations responsible for around 10% of the UK's emissions. The scheme features an annual performance league table that ranks participants on energy efficiency performance. The scheme is designed to tackle CO_2 emissions not already covered by Climate Change Agreements (CCAs) (where businesses receive up to an 80% discount from the Climate Change Levy (CCL) – a tax on the use of energy in industry, commerce and the public sector) and the EU Emissions Trading Scheme.

Processing traceability in food systems has been developed using assurance schemes that have often been associated with retailer safety and quality requirement. There is an opportunity for a greater understanding of traceability of domestic food waste which must be reduced to achieve sustainable food supply chains. However, our understanding of how consumers perceive and dispose of food waste is poor. Furthermore, potential solutions to 'sell by and use by' dates on food labels are not tested. These types of investigation can integrate wireless communication solutions with consumer science to provide an understanding of consumer behaviour and predictive models for the production of food waste.

We have presented evidence that demonstrates how food manufacturing and processing companies can assess and report sustainability of products. The databases and evidence required to support product accreditations for footprinting are becoming available through peer review research. There is an opportunity within the food industry to collect processing data during manufacturing and retail sectors. These data have been previously been used to determine the value and volumes of product flow. The opportunity now exists to integrate sustainability criteria with these data and this will result in new marketing opportunities. An important future development is to capture data regarding how consumers use food products in the domestic environment and incorporate them into diets. Initial research has shown that small changes to diet can have significant sustainability benefits by reducing GHG emissions and waste associated with foods. An example of this is the Livewell Diet developed by the Rowett Institute for the World Wildlife Fund that suggests a 5% reduction in meat and 10% increase in fruit and vegetables can improve sustainability of food provided to consumers. This approach presents an opportunity for the food industry to develop life style communications that not only address the nutritional benefits of balanced diet but also emphasize the sustainability outcomes. This type of approach will require the processing and manufacturing sectors to consider diet plans and portion control when products are designed. The need to consider whole supply chain and product life cycle during NPD will become essential if sustainable outcomes are to be

realized. Data capture of energy use during processing and manufacturing will become critical and the means to convert this data to sustainability criteria and footprint methods will result in improved business practices.

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3 Environmental Sustainability in Food Processing

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3.1 Introduction

The food industry is one of the world's largest industrial sectors, making it an important user of energy. Generally, fossil energy (non-renewable) consumption leads to greenhouse gas (GHG) emissions, and has resulted in global warming, perhaps the most serious problem that humankind faces today. Food processing companies use various processing techniques to create a wide variety of marketable, packaged goods from crop or animal products, which have become an important part of the modern diet in developed countries. Across the world, food supply, demand and diet composition vary from region to region depending on the national economy, cultural background and purchasing capacity. For instance the Japanese like well milled sticky rice (Deshpande and Bhattacharya, 1982), Americans prefer semi-milled long grain or brown rice, whereas people in the Indian sub-continent prefer well milled parboiled rice (Lyon et al., 1999).

There is an increased awareness that the more discerning of consumers are considering ecological and ethical criteria when choosing food products (Andersson et al., 1994). These consumers demand safe food of high quality

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that has been produced with minimal adverse impact on the environment (Boer, 2002). This, along with global food security issues, means that the food industry is facing increasing pressure to ensure that their activities are sustainable while maintaining or increasing profitability in the face of competition. There is a strong focus on conserving natural resources, reducing GHG emissions and improving the energy and food security (Garnett, 2010). The global food processing industry is adjusting to energy efficiency requirements driven by legislation and consumer demand to remain competitive.

The combination of population growth, a decreasing per capita land area and growing global energy demand is putting great stress on arable land, water, energy and biological resources to provide an adequate supply of food while maintaining the ecosystem services. Environmental load, food components and customer acceptance of food are dependent on the production, processing and distribution systems. Three million people are currently dying every year from food and water-borne disease, millions more becoming sick, with one-sixth of humanity reported to be hungry and malnourished (FAO, 2010a, b). This chapter will discuss the challenges faced by the food industry in ensuring that processed food can be continually produced in an environmentally sustainable way.

3.2 Environmental issues related to food processing

The major environmental issues to be addressed by the food processing industries fall within operational, consumer and corporate domains (FCI, 2007). The most common environmental issues in the food industry are related to food packaging, food processing loss, food wastage, energy efficiency, water consumption, quarantine activities, chemicals used in processing and cleaning, and waste management.

3.2.1 Packaging, food loss and food waste

Food losses take place in the production, processing and distribution stages of the food chain (Parfitt et al., 2010). Food losses at the end of distribution (retail and final consumption) are known as food waste, which relates to retailers and consumer behaviour (Parfitt et al., 2010). Gustavsson et al. (2011) noted that approximately one-third of edible food produced for human consumption is lost or wasted globally. They reported that in developing countries more than 40% of food loss occurs postharvest and during processing due to financial, managerial and technical limitations in harvesting, packaging, storages and distribution systems. On the other hand, in industrialized countries, more than 40% of the food losses occur at retail and consumer stages due to over preparation and/or expiration of safe consumption date. In developing countries, food wasted at

consumer level is minimal because of scarcity and economic constraints. Conversely, the abundance of cheap food and consumer attitudes towards it may lead to high food waste in industrialized countries. Food losses and wastes are estimated to be 95–115 kg/capita/year in Europe and North America, while only 6–11 kg/capita/year in Sub-Saharan Africa and South/Southeast Asia (Gustavsson et al., 2011). Food waste is important because it embodies GHG emissions, water use, energy and other raw materials used in growing, processing, storage and distribution. Juliano et al. (2010) reported that wasted mangoes contribute to 53% of the overall GHG emissions during production, distribution and consumption phases.

Packaging is a fundamental element of almost every product and a vital source of environmental burden and waste. Packaging isolates food from factors affecting quality such as oxygen, moisture and microorganisms, and provides cushioning during distribution and storage. Food packaging can retard product deterioration, retain the beneficial effects of processing, extend shelf-life and maintain or increase the quality and safety of food (Marsh and Bugusu, 2007), thus it is essential and beneficial while also having an environmental impact. Shiina (1998) computed a relationship between environmental impacts and loss of food (Figure 3.1) and concluded that there is an optimum amount of packaging or other means of quality control that balances impact against loss of food.

Food packaging accounts for almost two-thirds of total packaging waste by volume (Hunt et al., 1990) and approximately 50% by weight of total packaging sales. Materials used include glass, aluminum, tinplate, tin-free steel, paper, paperboard and plastic (including biodegradables) (Marsh and Bugusu, 2007). The packaging of food presents challenges to minimize and modify primary and secondary packaging (Henningsson et al., 2004; Ajinomoto, 2003; Hyde et al., 2001) while maintaining or increasing customer satisfaction and decreasing

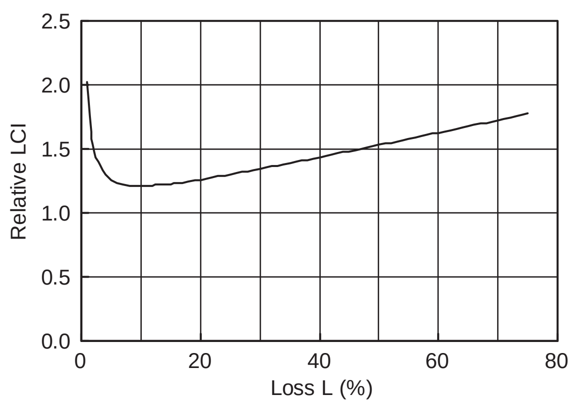

Figure 3.1 Relationship between relative LCI and loss in food supply (Shiina, 1998) (The relative $\mathrm{LCI} = (x1 + x2)/x3$; where x1 is production LCI, x2 is post-harvest LCI and x3 is production LCI without loss, if $x2 = x3/\text{loss in decimal}$). (Shiina 1998. Courtesy of National Agriculture and Food Research Organization, National Food Research Institute, Food Engineering Division, Japan).

environmental impact (Williams et al., 2008). It is argued that a reduction of 12% of raw materials can be achieved in the food and beverage industry and it makes a significant contribution to the profitability by improving yield per unit output and by reducing costs associated with waste disposal (Hyde et al., 2001). Increasing recycling rates and reducing weight in the primary package are environmentally efficient (Ferrão et al., 2003; Ross and Evans, 2003). Reusable glass bottle packaging systems are reported to be more environmentally favourable compared to disposable glass bottles, aluminum cans and steel cans for beer distribution (Ekvall et al., 1998). Modified atmosphere packaging is reported to be beneficial compared to a paper box and cold chain distribution for imported tomatos in Japan (Roy et al., 2008). Hence, food packaging should be done with a minimum amount of packaging materials that reduce food loss and maintain food quality with the lowest environmental impact.

3.2.2 Food processing and energy efficient technology

With the increase in global population it has been reported that as consumption surpasses production, the world's stocks of stored grain have been falling relative to each year's use (Roy and Shiina, 2010). The shortfall in food production and distribution not only increases food prices, but also increases the malnourished population which might lead to social and economic unrest. The World Bank estimated that the increase in food prices between 2005 and 2007 increased poverty by 3% on average, however the food processing industry must still reduce impacts (such as those measured by carbon and water footprints) of products while supplying healthy food within the buying capacity of consumers. Therefore, strategies for the future must be based on the conservation and careful management of resources needed for food, feed and fibre production and suitable processing. One option is the adoption of minimum processing to conserve the food grains and reduce environmental impact, hopefully with added health benefits as well. A change in rice processing and consumption patterns (e.g. from parboiled rice to untreated rice and from well milled to partially milled rice or brown rice) would conserve about 43–54 million tons of rice, reduce CO_2 emission by 2–16% (Roy and Shiina, 2011; Roy et al., 2011a) and reduce the threat of arsenic contamination (Roy and Shiina, 2011). Meat and dairy processing have been identified as high energy consuming sectors (Foster et al., 2006), and some processed ready meals are problematic because they have to be cooked and cooled more than once (FE, 2007). High pressure processing is reported to have advantages such as for caffeine extraction from green tea leaves, because of higher yields, shorter extraction times and lower energy consumption (Jun, 2009). The fuel mix can also be important, for example GHG emissions from food and beverage industries in Tasmania, Australia significantly reduced (0.42 kg in 2003 to 0.30 kg in 2005) following efficiency initiatives by a number of industry stakeholders (Harrington et al., 2008). Schnitzer et al. (2007) concluded that

application of solar thermal energy for industrial processes is promising and could provide an important step towards sustainability. The use of innovative technology or avoiding old technology which is widely used in developing countries and the adoption of minimum processing could improve production efficiency, minimize food loss, ensure food quality and reduce emissions. The energy efficiency of used machinery and old technology is usually low compared to that of modern and innovative technologies (NRDC, 2010). The improved efficiency of energy use and renewable energy sources will be essential to meet the growing demand of energy for sustainable food, feed and fibre production. Addressing the sustainability of the food processing industry requires broad cooperation among stakeholders to develop a comprehensive policy response. Smoothly functioning national and international food markets would ease pressure on food supply, and international support can help developing countries implement good policies and improve their food industries.

3.2.3 Waste management

The issue of direct food waste has already been discussed, but in addition to food waste and food loss, the food industry generates a significant amount of solid and liquid (organic and inorganic) waste from the production and preparation of food. The US Environmental Protection Agency estimated relatively constant rate of just over 2 kg (4.5 lbs MSW) per person per day since the 1990s (EPA, 2006). Generation of liquid effluent with high organic content, and the generation of large quantities of sludge and solid wastes are reported to be a common problem for all food industries (UNEP, 1995). Waste minimization in the food industry has led to improvements in energy efficiency, reduction of raw material use, reduction in water consumption and increased reuse and recycling on site (Hyde et al., 2001). Food processing wastes are now also being converted into high value by-products, or used as raw material for food or feed industries after biological treatment (UNIDO, 2010).

Rashid et al. (2010) noted that greenhouse gas emissions from organic food waste can be mitigated if it is applied to agricultural land as a nutrient source. Solid waste from food processing plants can be high in nitrogen, phosphorus and carbonaceous material, but unless properly managed can decompose slowly, and if anaerobically, produces methane gas and acidic leachate which have a significant environmental impact (WCC, 2010). It could be environmentally beneficial to utilize organic solid waste as an animal feed (unless it is contaminated with coagulants), for composting (Eco-EC, 2008; Muñoz et al., 2004) or biogasification (Hirai et al., 2000) instead of landfilling. Material recycling followed by incineration is reported to be a much better option than direct waste incineration (Nyland et al., 2003), while energy recovery can achieve better environmental performance than scenarios without (Bovea and

Powell, 2005). Reduction or elimination of wastes or pollutants at the source is also recommended (McComas and McKinley, 2008). Combined, these ideas indicate that an integrated waste management system needs to be adopted by the food processing industry to reduce overall environmental burdens of waste.

A significant contribution to waste from the industry is associated with water, which is used as an ingredient, cleaning source, conveyor of raw materials and the principal agent in sanitizing plant machinery and areas. Harmful wastes disposed of in pits or waterways can leach into groundwater and affect water quality for workers and the community (USAID, 2009). The effluent from the food industry often has high chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS); nutrients, pathogenic organisms, residual chlorine and pesticide. The clean technologies being adopted by the industry focus on source reduction, recycling, reuse and treatment of wastewater (Carawan, 1988; Ramjeawon, 2000; USAID, 2009; Shahabadi et al., 2009). High BOD and COD levels indicate increased amounts of product lost to the waste stream, but can also be related to ancillary factors like packaging. Talve (2001) concluded that production of packaging board and paper contributes about 25% of COD to the environmental impact of beer production. Thermal pollution of wastewater promotes the growth of organisms such as *Vibrio vulnificus* leading to an increased risk from handling or consuming fish grown in these waters. Temperature increase also facilitates methylation of mercury and subsequent uptake by fish (Paz et al., 2007). Theoretically pathogens, suspended solids, dissolved solids, nitrogen and phosphorus are removed in wastewater treatment processes. Ramjeawon (2000) advocated that wastewater (in this case the cane-sugar industry) should be separated into two or three streams to isolate the most polluted wastewater from the largest volume of relatively unpolluted water, thereby reducing the scale and expense of treatment required. This is important because wastewater treatment plants can contribute significantly to eutrophication potential (estimated to be $>30\%$ for the brewing industry by Hospido et al., 2005).

Similarly, separation of chemical waste from organic waste, and appropriate disposal to prevent chemical movement to ground or surface waters and separation of fats, oils and greases from solids are also recommended (USAID, 2009). In the UK, approximately 56% of the water industry's emissions come from wastewater treatment and 39% from clean water treatment and supply (McCarthy, 2008) therefore pre-treatment separation by the food industry has the potential to be highly beneficial as concluded by Carawan (1988) who suggested that waste load reductions is more economical than treatment processing.

Shahabadi et al. (2009) modelled wastewater treatment by the food industry and found that on-site biological processes made the highest contribution to GHG emissions in the aerobic treatment system. The combination of an aerobic reactor, anaerobic solid digestion with the recovery and use of the

produced biogas is recommended for food processing wastewater treatment. Higher BOD removal efficiencies are reported for aerobic or hybrid process compared to anaerobic (Shahabadi et al., 2009), but it is reported that anaerobic wastewater treatment minimizes methane loss for reuse of biogas, thus significantly reducing GHG emissions (Lexmond and Zeeman, 1995). Biofiltration is reported to be an energy-efficient and sustainable technology for VOC control in food processing, livestock farms, and so on (Kapse and Balomajumder, 2003).

The importance of these issues is illustrated by the processing of parboiled rice (PBR), which requires more water compared to untreated rice for soaking and steaming. Germinated brown rice (GBR) requires more water than PBR because it is used during germination and washing (to control odour) before it is cooked or packed (Roy et al., 2010). Although the effluents discharged from local rice mills do not contain any toxic compounds or pathogenic bacteria, repeatedly discharging them into open waters may become a public health hazard, as the stagnant water not only encourages a variety of organisms but also emits bad odours in and around the local area (Ramalingam and Raj, 1996). Relatively higher populations of total aerobic bacteria, staphylococci, lactic acid bacteria and yeast were reported in soaked water from the cold soaking method than the others. Modern rice mills are adopting hot soaking and where there is a continuous discharge of effluents, with a high COD, phenols and sugars, into a localized area there may be environmental concerns (Ramalingam and Raj, 1996). Growth of the PBR and GBR sectors may lead to water shortages and contamination at specific sites. BOD and COD in washed water is known to be higher for milled rice compared to that of GBR or PBR (http://www.musenmai.com/nichido.html). Malodours emitted from large animal production facilities and wastewater treatment plants may produce health symptoms such as: eye, nose, and throat irritation, headache, nausea, diahorrea, hoarseness, sore throat, cough, chest tightness, nasal congestion, palpitations, shortness of breath, stress, drowsiness and alterations in mood (Schiffman and Williams, 2005). Local communities may be unwilling to tolerate the processing industry if it detrimentally influences quality of life surrounding the production site. The US programme 'pay-as-you-throw' creates an incentive to generate less waste and increase material recovery through recycling and composting (Marsh and Bugusu, 2007). It seems that policy options to reduce waste impacts and increase sustainability of the food industry include both the alternate management options and regulations.

3.2.4 International trade

Although food miles are often used to identify environmental inefficiencies in food supply chains (Pretty et al. 2005; Foster et al., 2006), would not be the only determinant for the food industries since there is a wide variation in

the agricultural production in different parts of the world. Webber and Matthews (2008) also noted that transportation of food accounts for only 11% of the GHGs generated by the food consumed by an average US household annually. Sourcing food from a neighbouring farm in individual cases might reduce some transport related impacts, however, evidence for a lower environmental impact of local preference in food supply and consumption when all food types are taken into consideration is weak (Foster et al., 2006). Also, food miles are noted to be a poor indicator of the environmental and ethical impacts of food production (Edwards-Jones et al., 2008). In winter imported tomato (produced under plastic cover) from tropical countries would be environmentally preferable than local tomato produce from greenhouses (Carlsson, 1998; Foster et al., 2006; Roy et al., 2008). Similarly, wide variation in environmental loads of meat production stage is reported (Subak et al., 1999; Ogino et al., 2004, 2007; Núñez et al., 2005; Casey and Holden, 2006; Saunders et al., 2006; Williams et al., 2006; Nguyen et al., 2010; Beauchemin et al., 2010; Niggli et al., 2008; Pelletier et al., 2010), which may make imported meat environmentally superior to the domestic product in some countries.

Countries have set an ambitious goal of food self-sufficiency in food, however, it remains to be achieved in many countries including developed and developing countries. Japan has committed to raise her food self-sufficiency to 45% and 50% in 2010 and 2020, respectively, but fell to 40% in 2010 (JIN, 2000; Kyodo, 2011). The increasing population growth coupled with lower production and changes in consumption pattern aggravates the food self-sufficiency in most of the developing countries. Trade has an important role to play in improving food and nutrition security (WHO, 2010a). Although international food trade benefits consumers through year-round supplies and a greater quality and variety of food (Charles et al., 2011), it could also be responsible for new food safety risks (Buzby and Unnevehr, 2003) and raise costs due to the involvement of various parties (producers, inter-border traders and consumers). Food trade will continue to expand with growth in demand, increased market access and reductions in technical barriers (TMSA, 2011). It is worth noting that consumers might appreciate greater information on environmental impacts (carbon footprint) of food they purchase, which are associated with costs, but unlikely to pay more for sustainable food over non-sustainable ones. International trade might also improve the food quality worldwide and the developing countries need to maintain quality and adapt higher standards of food safety to compete in the international markets (Roy and Shiina, 2010). Flexible bilateral or international treaties are essential which might allow the countries to release their excess stock to the food deficit countries improving food security. Consequently, international trade, food quality as well as production costs have to be taken into consideration for the sustainability of food industries.

3.2.5 Health consciousness and balanced diets

The WHO has formulated a diet which depicts the dietaries and their sources for a healthy and balanced diet to avoid undernourishment and food related chronic diseases (WHO, 2003). It suggests that 10–15% of total human energy consumption should come from proteins and 10–25% of dietary protein should be of animal origin, that is, animal protein should contribute only about 2.2% of the total caloric intake if the average of the WHO recommended range is used. However, food supply from different sources varies from region to region (Figure 3.2). Food choices seems to be protein rich

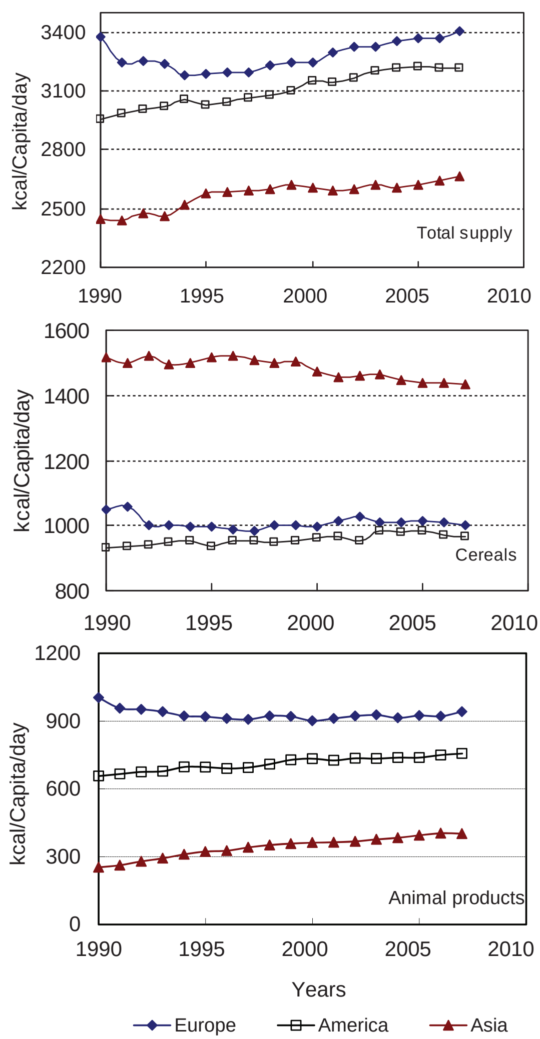

Figure 3.2 Trend of food supply from different sources in different regions (Data source: FAO, 2011).

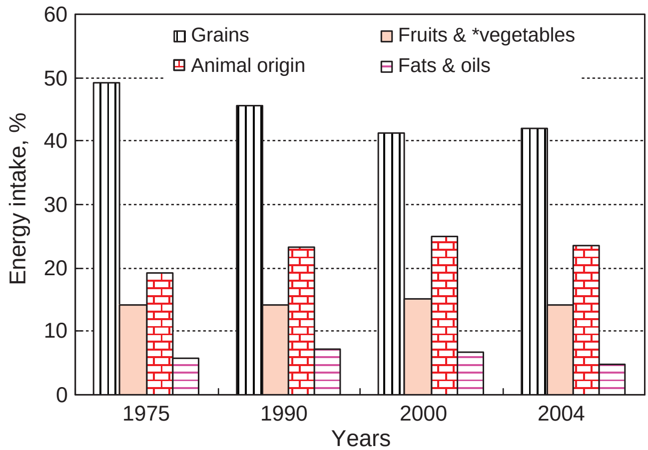

Figure 3.3 Trend of energy intake from different food source in Japan (*includes potatoes, legumes, seeds and nuts). (MHLWJ, 2004)

(especially, animal proteins) in most of the developed countries compared to that of developing nations, except wealthy populations in some emerging economic countries. In Japan, food from animal origin contributes about 23.5% and 53.4% of energy and protein intake, respectively in 2004 (MHLWJ, 2004) and the contribution of animal food is reported to be increased (Figures 3.3 and 3.4). Although consumption of food from animal origin has been increased, total food consumption declined even though an adequate amount of food has been supplied in Japan (Figure 3.5). Trends of being overweight and obese have also declined in Japan for all age groups, except the 60–80 age group (MHLWJ, 2004). The human health consciousness and improved health

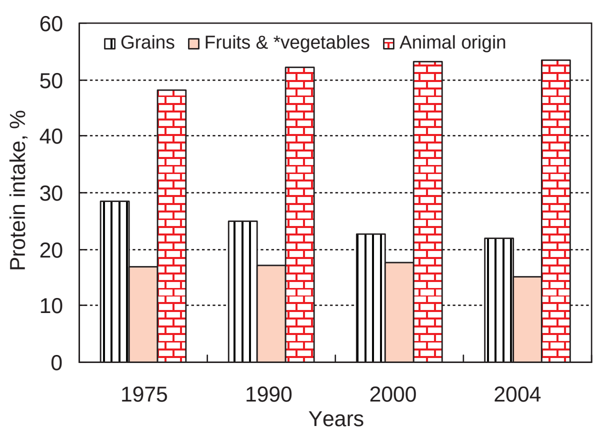

Figure 3.4 Trend of protein intake from different food source in Japan (*includes potatoes, legumes, seeds and nuts). (MHLWJ, 2004)

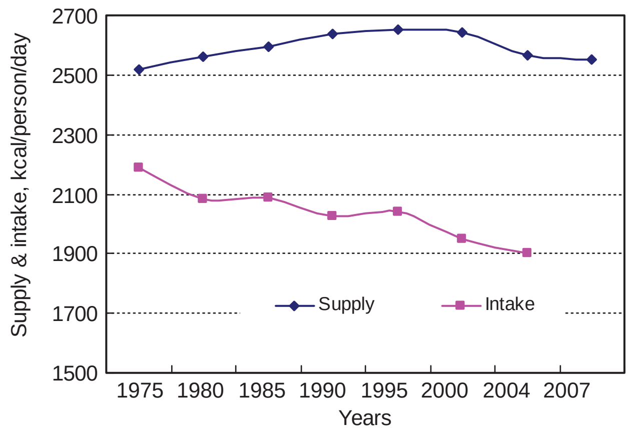

Figure 3.5 Food supply and intake in Japan (MAFF, 2008; MHLWJ, 2004).

systems might have played an important role in changing food consumption patterns.

The level of carbon emissions is noted to be affected by dietary choices (Carlsson, 1998; Reijnders and Soret, 2003; Eshel and Martin, 2006; McMichael et al., 2007; Davis et al., 2008; Weber and Matthews, 2008; Roy et al., 2009; Sharon et al., 2009; Millward et al., 2010). Environmental impact reduces if animal protein is swapped with vegetable protein (Carlsson, 1998; Reijnders and Soret, 2003; Håkansson et al., 2005; Davis et al., 2008). The life cycle environmental load of non-vegetarian meals is 1.5–2.0 times compared to the vegetarian meals (Pimentel and Pimentel, 1996; Reijnders and Soret, 2003; Pathak et al., 2010). Lacto-ovo vegetarian diets also reduce GHG emissions (Pimentel and Pimentel, 1996; Pathak et al., 2010). Per capita supply of vegetable protein is slightly higher in developing countries, while the supply of animal protein is three times higher in industrialized countries (WHO, 2003). Worldwide more than 1.4 and 0.5 billion people are overweight and obese, respectively (WHO, 2012). It is also predicted that about half of European adults will be obese by 2030 (IFIC, 2001). About a billion people in the world are suffering from hunger (FAO, 2010a, b) that is, one-sixth of humanity is hungry and malnourished. In contrast, a billion people are substantially over-consuming spawn in various chronic diseases (GO-Science, 2011). Consumption of beef and pork increases the risk of intestinal cancer (AICR, 2007), however, reducing the consumption of fatty meat may lower the risk of coronary heart disease (Li et al., 2005; Ding, 2006). A global transition to a low meat diet is also recommended for other health reasons (Stehfest et al., 2009; Sharon et al., 2009). Well-planned vegetarian diets are noted to be appropriate and healthy for all stages of life (Winston and Ann, 2009).

Diseases result in poor utilization of food calories after consumption enhance malnutrition through a combination of reduced food intake, malabsorption,

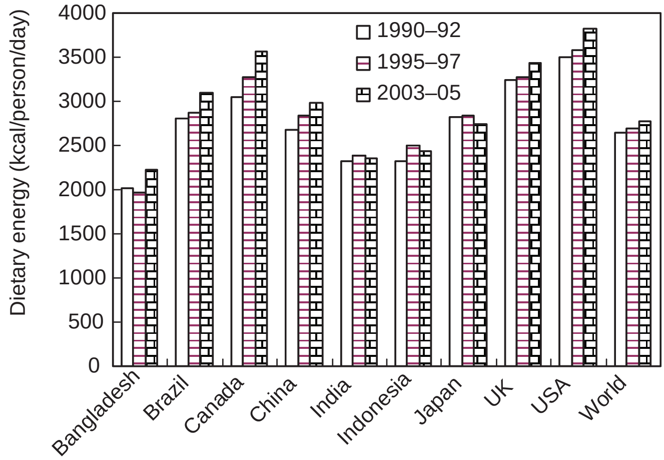

Figure 3.6 Food supply in different countries and in the world. (Data source: FAO, 2008)

anemia, and other nutrient loss (Tomkins and Watson, 1989). It may result not only in the effective waste of food, but also required medication, hence increase GHG emissions. If we are to reduce malnutrition around the world and prevent much human suffering resulting from the ever increasing demand on our food systems for nutrient resources, emphasis must be placed on adequate food production and consumption with the utilization of minimum resources. Although the recommended food intake is approximately 2200 kcal/person/day (9.2 MJ) for a healthy diet to avoid undernourishment (FAO, 2001), available food for human consumption was 2770 kcal/person/day in 2003–2005 (FAO, 2006). The average food supply is greater in developed countries and lower in some of the developing countries (Figure 3.6). Uniform food distribution in the world not only reduces human suffering by avoiding inadequate or over-consumption in some countries but also improves international trades. The changing trends in food distribution and consumption need to be considered to develop strategies for the sustainability of food processing industries and reducing environmental burden on the earth.

3.3 Greenhouse gas (GHG) emissions from food processing

GHG emission from food processing is dependent on the type of raw materials, processing, packaging and distribution, and adopted technologies in the industry. Although conventionally produced raw materials consume greater amounts of fertilizer and pesticides, organic agriculture, except organic sheep farming, requires more arable land leading to higher global warming impact, (Williams et al., 2006). The impact of conventional and organic pig farming systems are noted to be similar on a per kg basis (Basset-Mens and

van der Werf, 2005). However, Foster et al. (2006) argued that there is insufficient evidence available to state that organic produce would have a less environmental impact than that of conventional. Genetically modified (GM) produce improves productivity and reduces emissions (Bennett et al., 2004; *ScienceDaily*, 2005). GM food and feed improves nutritional and/or health characteristics (ILSI, 2004; Sten et al., 2004; Rhee et al., 2005; Halle et al., 2006; Lee et al., 2006). Although most of the studies on GM food or feed depict their benefits and no adverse effects were reported except for a few examples (Liu et al., 2004; Gizzarelli et al., 2006), strong opposition from different groups also exists and its use as food and feed is not widespread (Roy and Shiina, 2010).

Life cycle CO_2 from fresh tomato supply chains in Japan are reported to be 268–281 and 876–889 kg/t for tomatos grown under plastic cover and in a greenhouse, respectively and dependent on the packaging and distribution systems (Roy et al., 2008). Emissions from the life cycle of rice are also dependent on the processing conditions. The life cycle CO_2 emission increases gradually from partially-milled (milling 2%) to the parboiled rice (0.22–0.28 kg/kg-cooked rice) and also dependent on the packaging option. It is also noted that the partially-milled rice not only reduces the environmental load but also retains more food nutrients compared to the well-milled rice. A change in rice production and consumption patterns would be helpful to reduce about 2–16% of the negative environmental impact coming from the current life cycle of rice in Japan (Roy et al., 2009). The GHG emission during the life cycle of cooked rice is reported to be 2.8 times greater than that of chapatti, a product of wheat flour (Phattak et al., 2010). The environmental impact of beef is reported to be greater than that of pork or chicken (Roy et al., 2011b). It seems that sourcing of raw materials, processing and distribution systems may play an important role for the sustainability of the food processing industry.

3.4 Impact of climate change on food processing

Climate change can emerge as a new challenge in the area of food processing and food safety. Rise of ambient temperature reduces shelf life of food, increases risk of food poisoning and food spoilage unless the cold-chain is extended or improved (James and James, 2010). Currently, the cold-chain accounts for approximately 1% of CO_2 emission in the world, however, it is likely to increase if global temperature increases (James and James, 2010). Food safety hazards can evolve at any stage of food production, processing, distribution and consumption (Jaykus et al., 2008; Tirado et al., 2010a, b). It is thus important for the food industries to be prepared for these changes. If changes in atmospheric composition and global climate continue, there will be relocation of crops and their diseases (Chakraborty et al., 2000; Lobell et al., 2011; Linnenluecke et al., 2011). The transmission of food and waterborne diseases has become clear (McMichael et al., 2008; Jaykus al., 2008). Climatic conditions also affect productivity of crops, fisheries and aquaculture, livestock

performance and the functioning of ecosystem services in all regions (Ingram et al., 2008; Kang et al., 2009; Nardone et al., 2010).

Rising temperature and increased frequency of natural calamities puts severe pressure on food availability, stability, access and utilization, thereby increasing volatility in production and prices (von Braun, 2008). Wang and Frei (2011) noted that abiotic environmental stresses negatively impact crop productivity and are major constraints to global food security. Marques et al. (2010) predicted both chemical and biological risks in the seafood industry, a new challenge for the food industry and public health authorities to uphold consumer confidence and food safety. The risk of mycotoxins in temperate and aflatoxin in tropical regions will increase (Paterson and Lima, 2010). A tendency towards increasing concentrations in protein and antioxidants in stressed crops, and a loss in quality, starch and lipid concentration, or physical/ sensory characteristics are also identified (Wang and Frei, 2011). Climate change may also affect the socio-economic aspects related to food systems such as agriculture, animal production, global trade, demographics and human behaviour (Tirado et al., 2010a). The climate change would force relocation of the food industries if the supply of raw materials and consumer disruption takes place. Consequently, the food industry might have to modify its product lines and adjustment will also be required in product categories to be safe, sustainable and competitive in the emerging food markets.

3.5 Discussion

The food industry is now facing increasing pressure for environmental sustainability and the health and safety of the consumer. There is obvious potential to increase customer satisfaction and at the same time decrease the environmental impact of food packaging systems, if the packaging design helps to decrease food losses (Williams et al., 2008). Although food industries use huge amounts of water (Gilde, 1972; Foster et al., 2006), impacts on water resources are seldom included (Foster et al., 2006). It is noted that as water levels in rivers and aquifers fall, the concentration of pollutants increases, limiting the number of usable water sources, thus legislation and motivation is required which reduces water consumption (McCarthy, 2008). Consequently, emphasis should be placed on reducing the overall water use in food industries. Heller and Keoleian (2003) concluded that food-related illnesses and deaths are on the rise, demanding a reevaluation of the food processing and distribution system. Evidence from the health sector shows that changing diets is difficult but not impossible, and it requires concerted and committed actions, possibly over long timescales (GO-Science, 2011).

The food habit is known to be dependent on the accessibility/availability/ health concern/cultural and regional preferences and finally environmental concern. The minimum processing option which reduces food loss (Roy et al., 2008) could be very helpful in the developing countries or region where food

grains are scarce and abate malnourishment and improve food security. Conversely, this option may result in surplus grain in the developed countries, enable them to enhance their humanitarian aid (food aid) to the food deficient countries. Thus, initiative should be taken to motivate consumers in selecting minimum processed food, reduce or avoid foods that have greater environmental load than their alternatives, either domestic or imported, if that is not health hazardous and prohibited. The carbon footprint labelling may also help consumers select environmentally preferable food products. Simultaneously, there should be a message to have a healthy and balanced diet every day to avoid either obesity or malnourishment.

Strong purchasing capacity might enable selection of high quality environmentally sound products even though these are expensive, but with world economic slowdown and declining purchasing power people may be forced to buy cheaper/lower quality products either organic or conventionally grown which may have a higher environmental burden. Benchmarking coupled with specific processing operations and management practices leads to product innovation, enhanced competitiveness, and may ease operational cost and help regulators and industries to promote and implement cleaner production initiatives (Maxime et al., 2006). Extending the best practice in the food industry has the potential to make sharp improvements in sustainability across the food system. Moreover, even distribution may also help to improve food security in regions where food products are scarce and may also enhance the international food trade. Understanding the local, regional and international demand, availability of raw materials and consumer preference will be crucial for the environmental sustainability in the food industry. The gross domestic production (GDP) has a strong effect on food consumption (Roy and Shiina, 2010). Figure 3.7 depicts the effect of GDP on the food supply in Japan, which

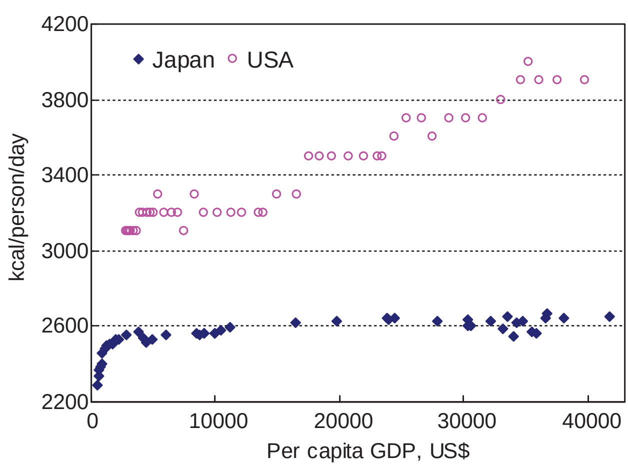

Figure 3.7 Relationship between GDP and food supply in Japan and USA (Poritosh and Shiina, 2011. Reproduced with permission of Nova Publishers).

can be used as a guide to estimate demand of food in developing countries, especially in Asia and may help the food industry to be competitive and sustainable. The food industry has the potential to mitigate environmental pollution through raw materials by sourcing and management approaches, use of efficient and innovative technologies, providing information on environmental impacts of food products, and promoting environmental awareness. Finally, the LCA methodologies, especially the 'carbon footprint' can be used as an effective tool to ensure environmental sustainability of the food processing industry.

3.6 Conclusions

This study revealed that the food industries have the potential to reduce their environmental burden by adopting alternate production, processing, packaging, distribution and waste management, and promoting sustainable food products. The fierce competition, consumer demands, food safety concerns and environmental legislation forces the food industry into innovative and efficient processing and packaging technology. Careful attention needs to be placed on raw material sourcing, which can be either organic or non-organic, local or imported without compromising their quality and safety of food products and their environmental impacts. Labelling of the carbon footprint and information on balanced diets would also be one of the most important issues that have to be encountered in the near future to empower consumers to make a decision for environmentally sustainable healthy and balanced food. The changing trends in food consumption also need to be considered to develop strategies for the sustainability of the food processing industry. Although efforts are underway to improve the environmental sustainability of the food processing industry, a network of information sharing and exchange of experience may expedite it.

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4
Life Cycle Assessment and Sustainable Food Processing

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4.1 Introduction

In the broadest sense, 'sustainable food processing' implies a system to take a foodstuff and convert it into something different (and presumably more desirable) in such a way that the process can be continued almost indefinitely because it is not restricted by energy, other resources or cost. The phrase implies that the energy used to drive the process is minimal or renewably derived, the water utilized is not wasted or contaminated, the resources consumed are recyclable and reusable and that the cost is such that profit can be made, thus making a positive contribution to society. When we consider a discrete activity such as food processing, we tend to think of a factory designed for a specific purpose at a fixed location. From the first stages of planning through to construction, commissioning and operation the environmental impact of the plant has to be considered in terms of legal compliance with environmental and health and safety issues. Perhaps the most common methodology used to assess environmental consequences of plant infrastructure is the site-specific Environmental Impact Assessment (Morgan, 1998). An alternative approach that we can take is to consider all the environmental impacts associated with the product that is passing through the factory, a concept known as 'life cycle thinking' (lct.jrc.ec.europa.eu), whereby we consider the production of raw materials and energy, construction

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of manufacturing stages, production, distribution, sale and consumption, and finally its disposal as waste or recycling to a new product (ISO 14040, 2006). The purpose of life cycle thinking is to avoid small-scale focus on the local geographical situation at any particular point in a product's life cycle (e.g. the processing plant) and to avoid burden shifting. Burden shifting is a situation where an action to reduce one type of environmental impact either increases another type of impact, or moves the impact to another geographical location.

Life Cycle Assessment (LCA) is a specific, quantified methodology utilizing life cycle thinking. The International Standards Organization defines LCA as 'a technique for assessing the environmental aspects and potential impacts associated with a product, by – compiling an inventory of relevant inputs and outputs of a product system; – evaluating the potential environmental impacts associated with those inputs and outputs; – interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study' (ISO 14040, 1997), and defines a specific set of guidelines for conducting a LCA study (ISO 14040, 2006; ISO 14044, 2006). Rebitzer et al. (2004) consider LCA as a 'methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product, such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise – and others'. LCA is typically described in terms of a generic system diagram indicating the components (Figure 4.1) from cradle-to-grave. LCA is normally focused on *products*, but the methodology can be adapted to *processes* and *services* (Roy et al., 2009), and therefore can be applied to food processing rather than just food products.

There is a wide range of environmental assessment methods, summarized for dairy production systems by Yan et al. (2011) (Table 4.1). The differences

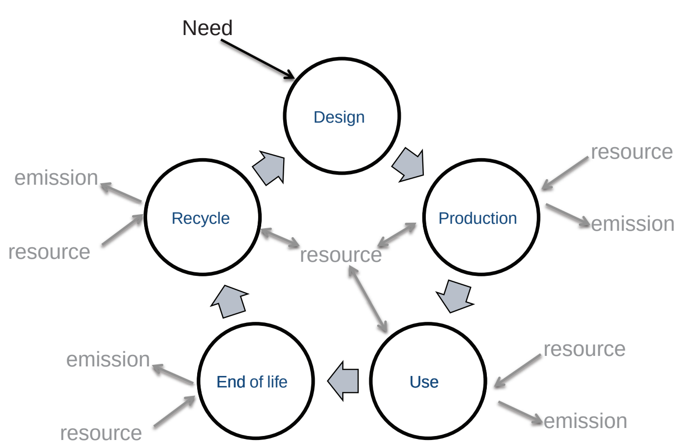

Figure 4.1 An example of a generic cradle-to-grave/cradle LCA system.

Table 4.1 Summary of example environmental assessment tools that can be used for the food chain indicating the focus, scale at which it can be deployed and overlap with economic analysis

Method	Focus	Scale	Economics
Life Cycle Assessment	Product	Any, tends to global	× and ✓
Multi-Agent System	Resources	Local to regional	✓
Linear Programming	Optimization	Local to regional	× and ✓
Environmental Impact Assessment	Risk analysis	Any, tends to local	✓
Agro-Ecological Indicators	Input-output accounting	Any	×
Ecological Footprint	Consumption rates	Global	×
IPCC inventory	National flux	National	×

between these approaches are found in the focus, be that practice or product, the purpose and the spatial scale at which they operate. LCA is the only common approach that can be applied, sometimes simultaneously, across a range of scales (Ecological Footprint (Thomassen and De Boer, 2005; Rees, 2000) and Agro-Ecological Indicators (Bockstaller et al., 1997) being the others), and which is focused on the product rather than the practice. All the methods, however, give priority to the environment, but LCA has a broad scope considering the environmental impacts of a product, process or service on natural capital, human health and resource use (Basset-Mens et al., 2009). As with all environmental assessment methods, the focus of LCA is substantially less broad in scope than that required to address sustainability, which encompasses the social, economic, productive and environmental functions of a system (Basset-Mens et al., 2009). LCA can be extended to consider some social functions (UNEP/SETAC, 2009) and economic costing (in the form of Life Cycle Costing, Klöpffer, 2008), but does not currently have integrated interpretation methods to properly balance these with the environmental impacts. Sinclair (2011) suggested that decision support processes such as multi-criterion decision analysis, multi-objective decision making, cost-benefit analysis and LCA can all be applied to sustainability assessment, but all have flaws such that no one approach can be regarded as complete. There is probably more scope for developing LCA as a tool for sustainability assessment than most other environmental assessment tools currently available because the theoretical framework is defined and agreed as an international standard.

The added value of LCA for the agri-food industry, and businesses involved in food processing probably lies in the realm of eco-labelling and Environmental Product Declarations (EPD, Schau and Fet, 2008; ISO 14025, 2006). An EPD is designed to communicate the environmental performance of a product or system with the expressed intention of permitting comparison between products. An EPD can be used to inform consumer choice or supplier choice within a production chain. An EPD is defined by product category rules (PCR) that are specific rules, requirements and guidelines for undertaking an

LCA of one or more products (the 'product category') that fulfil equivalent functions. PCR details the functional unit, system boundary, impact categories, data quality and any other parameters specific to the product. Within the food sector, PCR for EPD have been defined for agricultural production of food stuffs and a range of food products (www.environdec.com). Taking the example of processed liquid milk (2010-06-24, PCR 2010:12, di Stefano, 2010), the PCR encompasses upstream production (all activities associated with the milk production at the farm), core processes (pasteurization or equivalent and packaging), transport to shops and optionally, the consumption of the milk (Figure 4.2), and defines a minimum set of characterization data, emission factors and environmental impacts that must be considered.

It is worth noting again that EPD and LCA are primarily *product* focused, thus *processing* is usually one small component of the whole system. However one of the specified uses of LCA is hotspot analysis, which is the identification of places in the systems that generate products that are responsible for a high proportion of environmental impacts. A related purpose is to interrogate a production system to improve the environmental performance of all components. For food products, the processing stages will perhaps be quite important, even if they appear to contribute relatively little to overall environmental impacts when compared to the agricultural production phase (IDF, 2009). There is a generally recognized design and deployment cycle that most companies will use to some extent when

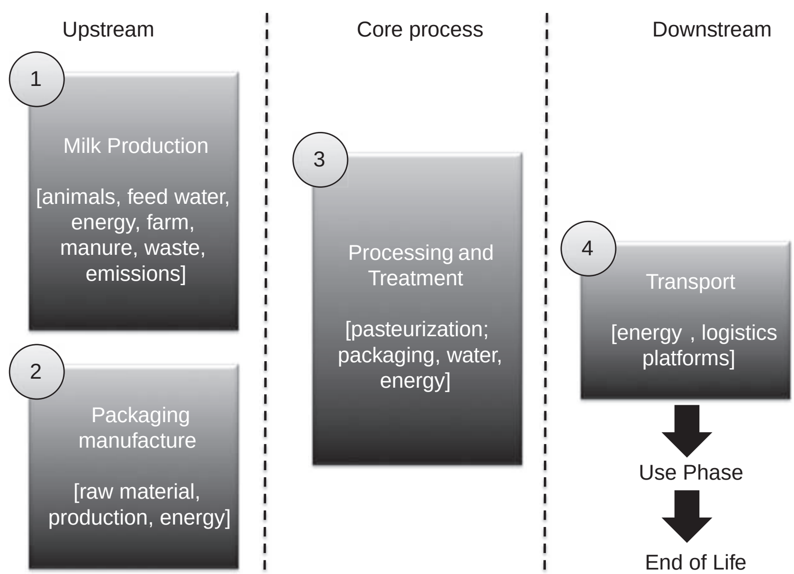

Figure 4.2 Schematic of the system included in the Environmental Product Declaration for liquid milk.

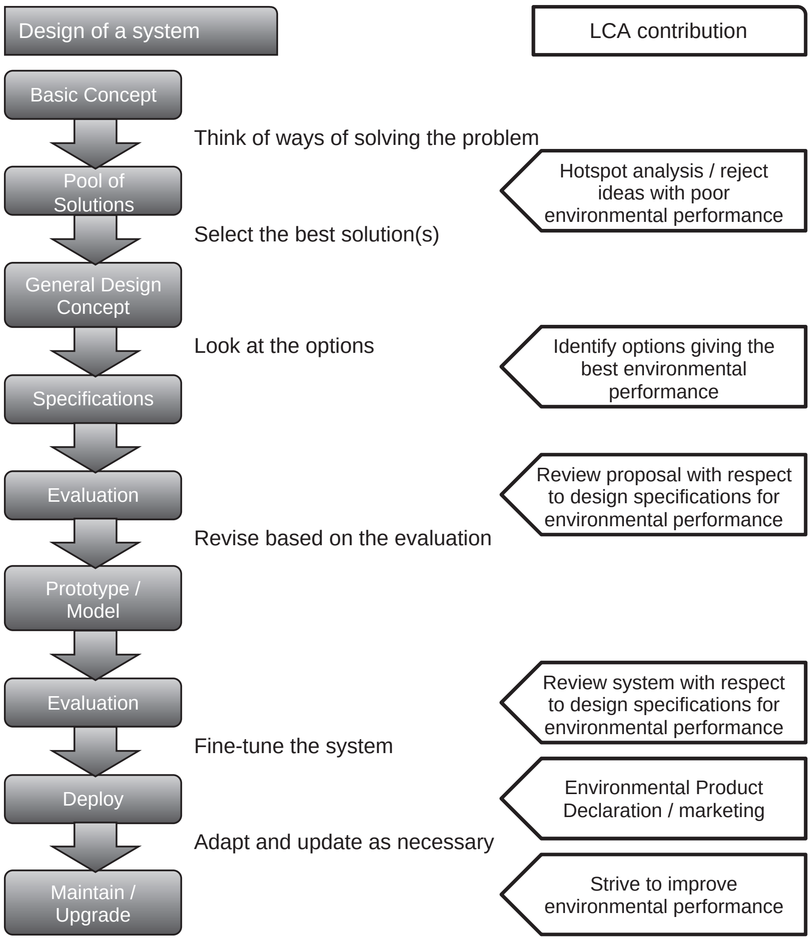

Figure 4.3 Schematic representation of a typical design process.

evaluating how to change processes or develop new ones. There is much scope for LCA and later EPD as part of the design cycle for food processing (Figure 4.3).

While there have been many thousands of LCA studies published over the years (see Yan et al. (2011); Roy et al. (2009); Hospido et al. (2010) for some examples spanning various sectors), the vast majority of these have not been complete LCAs considering a range of impact categories, and almost none have considered all the dimensions of sustainability. For both consumer and business information truncated LCA methods have become popular with the focus on single impacts such as Carbon Footprint (total greenhouse gas emissions in CO_2 equivalents) (Carbon Trust, 2008; Flysjö et al., 2011), Water Footprint (also known as virtual water content, the total water

consumed) (www.waterfootprint.org), Energy Footprint (the total non-renewable energy consumed) (Wiedmann, 2009) and the Ecological Footprints (the quantity of biologically productive land required) (www.footprintnetwork.org; Vintila, 2010). The downside to 'footprint' type analysis is the major strength of LCA, that is, avoiding burden shifting, is no longer possible. The 'footprint' approach has gained popularity partly because they can be generalized, and simplified methods have been developed that are relatively easy to deploy. For example a Carbon Footprint can be calculated from a complete LCA (e.g. Casey and Holden, 2005), using a method such as PAS2050 (Carbon Trust, 2008) or an online tool (e.g. www.nature.org/greenliving/carboncalculator/index.htm; footprint.wwf.org.uk/), but the latter tend to be too general or focused on households to be of much use for system analysis. Likewise while there are few published examples of water footprint, ecological footprint and energy footprint, in general these focus on products rather than processes, and in some cases the detail of process and its contribution to impact is lost. Perhaps the biggest disadvantage of footprint analysis is the lack of integration. A complete LCA will use the same data, with similar quality and uncertainty for all impact assessments so the interpretation with regard to impacts and burden shifting is probably going to be more reliable than using unrelated footprint results in combination.

There are a number of issues related to using LCA for product, process or service evaluation, the most important of which is the tendency for a lack of comparability between results of different studies despite the fact that most are based on an International Standard (ISO 14040, 2006; ISO 14044, 2006). With specific regard to food products, Schau and Fet (2008) identified problems that were comparable because of differences in the nutritional quality of products from different systems and suggested the use of a quality correction to account for fat, protein and carbohydrate contents rather than just mass or volume produced. A review of milk production LCA (Yan et al., 2011) indicated that quality correction was generally applied for comparison, but that it was still very difficult to compare studies because of differences in system boundaries and impact methodology. These difficulties are, however, outweighed by the advantages LCA offers. As a tool that can contribute to developing sustainable food processing systems LCA allows us to understand how a process influences the impact of a whole system, how a local choice can have a global chain of consequences and how different impacts interact. It also forces design engineers to confront the important concepts of value judgements and the relationship of people (and society) with the food eaten and the systems demanded to deliver that food.

In the remainder of this chapter we will outline LCA methodology, review examples of LCA studies of selected food products with a range of processing components and we will evaluate the degree to which LCA is and can contribute to developing sustainable food processing systems.

4.2 The LCA methodology

4.2.1 Types of LCA

There are a number of types of LCA that we can undertake to analyse the environmental burden of a product, process or service. The concept of LCA as described by ISO 14040, 2006; is normally referred to as 'attributional' LCA (ALCA). ALCA is a static modelling approach that describes inputs (of resources) and outputs (of pollutants) of system that can be *attributed* to the delivery of a specified amount of product, process or service (Rebitzer et al. 2004). ALCA generally implies that a descriptive, full life cycle is being considered using average data, allocation of resources and pollutants in proportion to their use in the system and a retrospective viewpoint (looking towards the past). 'Consequential' LCA (CLCA), while not necessarily being a fully dynamic modelling approach, attempts to estimate how inputs (resources) and outputs (pollutants) change in response to a change in output of the product, process or service (Ekvall and Weidema, 2004; Rebitzer et al., 2004), and requires data that will reflect the internal changes in a system in response to changes in the outputs it creates. By definition CLCA is change-oriented and takes a prospective viewpoint (forward looking) because it aims to identify the consequences of choosing particular options. The difference between ALCA and CLCA has been visualized (Figure 4.4) in terms of trying to identify what burden is due to a system vs. how the burden changes with a change in the system. This idea has been described by Thrane (2006) in terms of CLCA defining the system with respect to causal relations with markets vs ALCA defining the system in terms of physical flows. Hospido et al. (2010) suggest that if LCA is being used for assessing novel food products then a *prospective attributional* approach is required that looks to the future to see how new products might interact with the environment. Sandén et al. (2005) also raised the idea of the technical generality of LCA: it can be specific to a product or plant or it can be generalized in the broad terms of a technology.

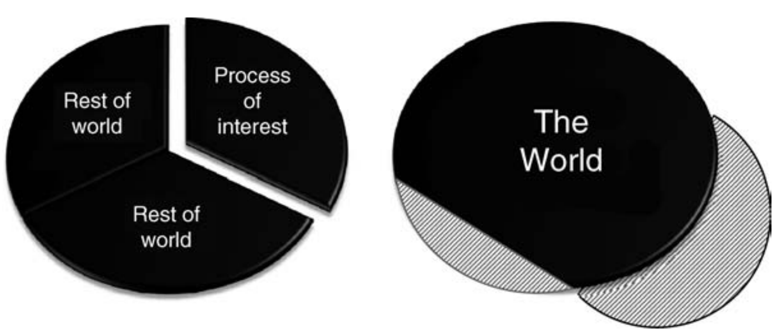

Figure 4.4 Schematic representation of attributional LCA (left) and consequential LCA (right).

A third type of LCA which is conceptually very different from ALCA or CLCA is Economic Input-Output LCA (EIO-LCA), which is an extension of the economic method of Input-Output Analysis and its resulting Input-Output Tables (IOT) (Finnveden et al., 2009). An IOT states in monetary terms for each economic sector, how much is bought from other sectors for each unit produced, thus if linked to resource use and environmental emissions it can be used to estimate the environmental burden of the supply-chain required by a specific sector (Finnveden et al., 2009). As EIO-LCA works at the sector/national scale it has not been widely used to investigate individual products, processes or services. There have, however, been a number of attempts to develop disaggregated and hybrid approaches where process based LCA and EIO-LCA are combined to gain a broader understanding of impacts for a particular process within a sector (e.g. Inaba et al., 2010; Crawford, 2008).

Within the context of sustainable food processing there is scope for most approaches to LCA. As part of a system design cycle we could use ALCA or CLCA with specific foci as required. For product branding and consumer information a retrospective, technically specific ALCA would be most useful. For strategic business management CLCA may prove most beneficial and for sectoral and national policy development EIO-LCA and hybrid LCA methods are probably most useful.

For the remainder of the discussion in this section we will focus on ISO standard ALCA methods because these are the foundation for all process-based methods and the four stages of the modelling process are used in the vast majority of LCA studies related to the food industry. It is essential for us to recognize at this early stage in the discussion that an LCA study is usually cyclical, thus the practitioner's intentions can, and often will, change as their understanding of the subject matter evolves. When considering the four stages of an LCA we should recognize that the first ideas adopted will not necessarily be the final ideas reported and that it is quite acceptable to adapt the study as it progresses. We should be rigorous in documenting such adaptations during the process.

4.2.2 Goal and scope

Despite the existence of an ISO standard, there are a number of studies and reviews that reveal a lack of comparability between LCA studies (e.g. Yan et al., 2011). The first step in the methodology is designed to ensure that the end-user knows exactly what the study was for and how it was conducted to ensure that their expectations are in line with those of the practitioner responsible for the study.

The *goal* of an LCA study should define: (i) the intended application; (ii) the reasons for carrying out the study; (iii) the intended audience; and (iv) whether the results are to be used to make comparative assertions. The intended application encompasses ideas such as simple impact assessment ('footprint'

analysis), total environmental impact assessment or hotspot analysis. This is intimately linked to the reason for the study, which might include better design, gaining competitive advantage or perhaps to optimize a production process for environmental and/or economic performance. Common applications and reasons for undertaking a study associated with food processing include weak point analysis, development of new materials, optimization of materials by analyzing system performance, decision-making for marketing, optimization of the production of a component, comparison of components, optimization of a product in its life cycle, assistance with strategic decisions and policy development. The specification of an intended audience is required in the goal to ensure that the end user can gauge the context of the interpretation and understand the report at the end of the study. An LCA aimed at consumers or company directors might require a completely different communication style to one aimed at designers, scientists or production engineers with specialist knowledge and a different appreciation of the system under study. A clear statement about whether a study is intended to be used for comparative assertions is required to allow the reader to decide whether bias might have crept in or if acceptable levels of comparability have been achieved. As the study progresses it is reasonable to change the goal if necessary, perhaps due to data or technical limitations or because the original question becomes redundant with new understanding, but it is essential for the final report that a coherent goal is stated that relates to the work that follows.

The *scope* of a study describes the technical implementation used for the LCA modelling. While the goal considers the ‘who’ and ‘why’ of a study, the scope addresses the ‘which’, ‘what’, ‘where’, ‘when’ and ‘how’. The purpose of explicitly describing the scope is to ensure both the author (while undertaking the study) and the end-user (afterwards) know exactly what the intentions and limitations are. It is possible to adjust the scope as part of the study cycle. The scope of the study should clearly describe:

(i) The product/process/service system – this should be as concise yet accurate and precise as possible.
(ii) The function of the system – to ensure the end-user knows exactly what the system does – many simple ideas prove to be quite complex once considered in light of function, for instance food packaging has multiple functions (e.g. protection, preservation, marketing, transport), therefore when comparing packaging options it is necessary to ensure that all options offer similar functions.
(iii) The functional unit – in order to scale environmental impacts of a system, quantitative measures have to be defined that relate to the described function – if we want to know the impact of a light bulb we can consider it on a piece basis (i.e. per light bulb), but this would ignore the fact that light bulbs are different in terms of power output, lifespan and other properties, therefore the functional unit of a light bulb should

perhaps consider the area to be illuminated (m^2), the amount of light required (lumens), the duration of illumination (hrs) and maybe the quality of light as a colour temperature (K) (Weidema et al., 2004).

(iv) The reference flow – the throughput of the system required for it to function, for example, the number of light bulbs and their specification required to achieve the functional unit, which becomes the basis for all subsequent modelling.

(v) The system boundary – ideally the system model should encompass four stages in the life cycle ('cradle-to-gate', or according to more recent thinking 'cradle-to-cradle', see Figure 4.1): raw material acquisition, manufacturing, use (including reuse and maintenance) and recycling/ waste management (Figure 4.5). In the context of sustainable food processing, the LCA must focus on the manufacturing stage and the practitioner must ensure that high quality, reliable data are available for this stage in the system. In practice it is common to ignore parts of the systems with a focus on the manufacture and perhaps use phases ('gate-to-gate'). When defining the system boundary three levels of contributors to the system are typically considered: primary contributors, which are activities directly related to the making, using or disposing of a product, material or service (material, processes and transport); secondary contributors, which are auxiliary processes, products or materials that have to exist for the primary contributors to exist; and tertiary

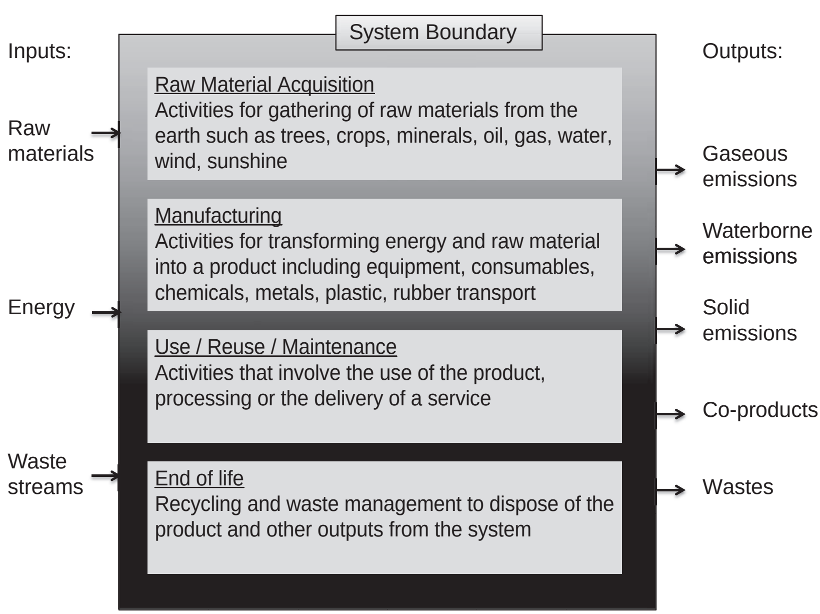

Figure 4.5 Schematic representation of the general requirements for defining the system boundary, processes stages and flows for LCA following ISO standards.

contributors, which are capital goods owned by the business that permit it to function. In the case of the capital goods we might ask whether, when doing an LCA of a glass bottle, do we need to include the photocopiers in the sales office? The capital goods or infrastructure are typically not included in LCA models and most LCA software allows for their explicit exclusion from inventory and impact calculations. In typical academic studies the system boundary tends not to be set as cradle-to-grave, but rather to focus on a specific phase of the life cycle, such as 'cradle to retailer' (Blengini and Busto, 2009) or 'cradle-to-destination port' (Pelletier and Tyedmers, 2010).

(vi) Allocation procedures – the concept of allocation arises in LCA because most systems and their components do not have a single function. For example a basic input to food production such as a cow produces milk, meat, leather, tallow, offal and other minor products or wastes. If we wish to calculate the environmental burden of milk we need to include the cow in the supply chain, but we cannot attribute all of the impacts of the cow to milk as some have to be attributed to the other products or functions that the cow serves (these could potentially include grass sward maintenance (Fitzgerald et al., 2005) and aesthetic appeal of the rural environment at the extreme). This attribution is known as allocation. According to ISO 14040 (2006) and ISO 14044 (2006) it is desirable to avoid allocation by splitting, which is not normally possible, or by system expansion where the model is expanded to account for multiple methods of producing all of the outputs of the system followed by a credit calculation (Figure 4.6), however the vast majority of LCA studies to date have used allocation of one kind or another. The simplest

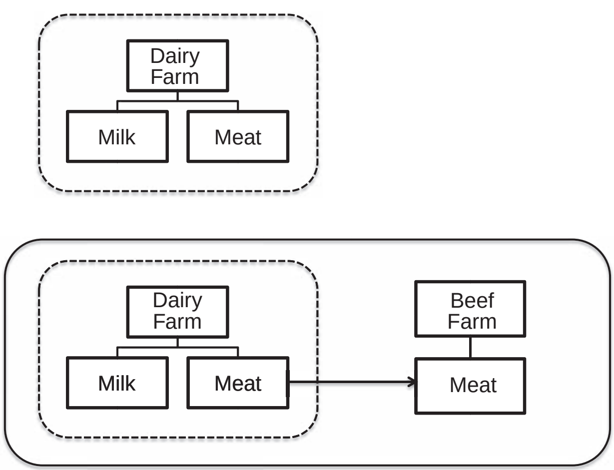

Figure 4.6 Schematic illustration of allocation (top) vs. system expansion with avoided burden (bottom).

method is physical allocation based on mass (or perhaps volume), but slightly more complex biophysical methods are also possible. For systems where the value and mass of the co-products is very different mass allocation only makes sense if the more valuable product has the greatest mass, as it is usually the reason for the system to be created in the first place (think of diamond mining). Allocation based on market prices (economic allocation) is commonly used because data are readily available and there is an instinctive belief that the environmental impact should reflect the economic value of a product. As a general rule, economic allocation should only be used when prices are stable in an open market (i.e. the price reflects a free value for the product rather than being dictated by other factors) and there is an approximate linear relationship between market value and the masses or volumes of concern. The impact of allocation can be seen in studies by Casey and Holden (2005) when the carbon footprint of Irish milk was estimated to vary by around 15% depending on allocation approach and by Svanes et al. (2011) who found that economic allocation gave a wider range of results for LCA of wild caught fish, and that the allocation approach would lead to different behaviour by market actors. Thus it is essential that allocation be valid and not merely convenient when used. Ideally allocation is not used at all. For simple burden accounting (attributional LCA) allocation is usually satisfactory, but for consequential modelling 'system expansion' is preferable because it allows flexibility in crediting impacts within the model.

(vii) Data requirements – this section of the scope should clearly set the minimum standard for data to be used in the study. Data can come from surveys, national statistics, estimates and guesses. The rigour with which the data have been compiled and reviewed must reflect the intended goal of the study. For a comparison of commercial products the scope should not permit guesses and unverified data to be used. For a quick 'look-see' as part of an internal assessment of a processing system, such data may be entirely appropriate.

(viii) Data quality – in general it is recognized that data are not always ideal for a given study. At the outset the quality of data aspired to should be clearly stated in terms of spatial and temporal representation, technological specificity and validity. This aspiration may need to be modified during the study as the quality of data actually available becomes apparent.

(ix) Assumptions – all assumptions being made during the study must be documented. At the outset some key assumptions may be identified, but as the study progresses and the model evolves it may be necessary to continuously revisit the scope document to revise the assumptions being made. It is important to realize that assumptions have to be made in nearly all studies, and in many cases guesses and estimates are also required. It is essential to record all such decisions to allow the reader of

the LCA report to be fully informed of any issues or limitations that may be important. The ISO standard does not define a minimum data specification, but it does define a minimum requirement for honest reporting of the quality of the data used.

(x) LCIA methodology and types of impacts – The Life Cycle Impact Assessment (LCIA) phase of an LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases and should address ecological issues, human health effects and resource depletion as a minimum. There is a wide range of Life Cycle Impact Assessment methodology available to choose from and within each method there is also a range of impact types that can be considered. We will discuss these later, but it should be noted that they are defined initially when specifying the scope of the project.

(xi) Interpretation – the approach that will be used should be specified in the scope. It should address the identification of 'significant issues' (i.e. those aspects of the inventory that make the greatest contribution to the final outcome, any decisions made during the inventory compilation that might have influenced the results), and an 'evaluation' of the data to include a completeness check, a sensitivity analysis and a consistency check. The scope should outline how these will be conducted and also note any issues specific to the conclusions that can be drawn from the study.

(xii) Value choices and optional elements – this section of the scope should clearly specify where subjective decisions have been made based on values. It is critical to understand that the values of one society may be completely different to those elsewhere so the specification of such choices must be clear to the reader in the same way that assumptions must be clearly documented.

(xiii) Limitations – known limitation of the study should be clearly stated for the reader to judge.

(xiv) Type of critical review, if any – any study that involves comparison should include an independent critical review to provide the end user with some reassurance that the work is not unduly biased and has been conducted to a suitable standard for the goal and target audience.

4.2.3 Life Cycle Inventory

The Life Cycle Inventory (LCI) is the first step of the actual modelling stage of LCA. During this stage a system diagram is constructed that represents the flow of mass and energy in the system. Conventionally the system is split into processes, each of which has defined inputs and outputs, and data are then collected to quantify each flow. From these data the environmental burden of the system is calculated.

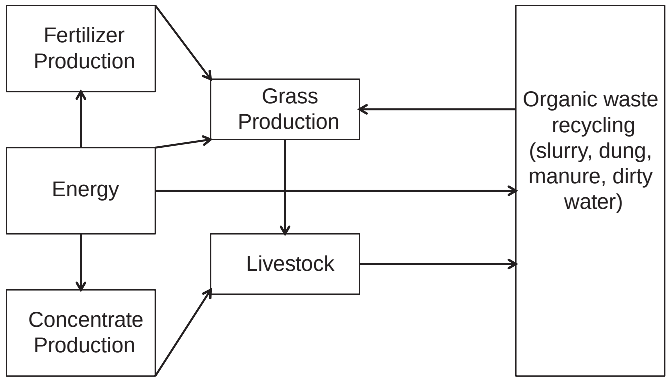

Figure 4.7 Schematic of broad general processes for LCI.

In order to build the LCI the flow chart is critical. Most food processing facilities will have extant design diagrams and process control diagrams that can form the basis of an LCI. The diagram should clearly define the system boundary (as defined by the Goal and Scope) and each major process. The diagram should be a simple as necessary for the study, ranging from broad general processes (Figure 4.7) to detailed processes closely related to mechanism (Figure 4.8). It is usually necessary to subdivide the system diagram into major component processes in order to collect data that are useful for LCI.

Each process in the LCI should be described in terms of: energy inputs, raw material inputs, chemical inputs, product or service outputs and emissions to air, water and waste (Figure 4.9) (Baumann and Tillman, 2004). The inputs

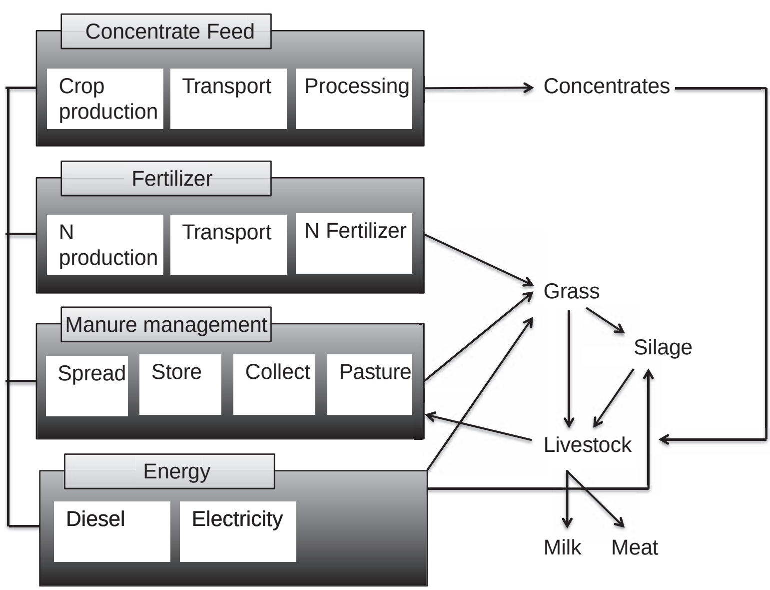

Figure 4.8 Schematic of processes closely related to mechanism for LCI.

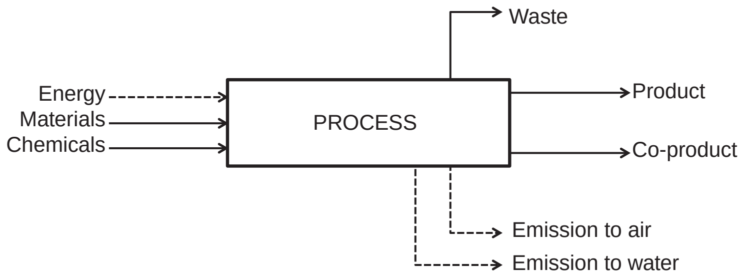

Figure 4.9 Material balance for processes.

and outputs for the process can be classified in terms of being in the technosphere, that is the energy or mass involved in the process (including products of interest, other products and waste), or between the technosphere and the ecosphere (environment), which result in pollution. Each process and the data that describe it can be regarded as either being foreground, which usually means close to that part of the system that is responsible for the output of interest, or background, which means processes that are quite distant in space and/or time from the functional unit. For ALCA modelling it is most common to use average data that represent classes of processes or products rather than specific instance data (e.g. a specific cheese from a specific factory vs. a class of cheese such as cheddar vs. cheese in general).

For most companies it will be relatively straightforward to capture technosphere data for their own processes because there will be a bill-of-materials for most products and economic costs and machinery specifications that can be used to describe energy consumption. In many cases such data can also be readily acquired from suppliers, but capturing polluting losses to the wider environment and from the downstream consumer and waste management data can be difficult, because these are data that most companies do not collect. There is now a wide range of databases with standard values for typical or average processes that represent common activities for specific sectors (Table 4.2). Most

Table 4.2 Examples of LCA databases (open access and commercial) that can be used to build LCI data tables for specific LCA projects

Database	Source
EcoInvent	www.ecoinvent.ch
LCA Food	www.lcafood.dk
Plastics Europe	lca.plasticseurope.org
ECLD	lct.jrc.ec.europa.eu
National Renewable Energy Laboratory (NREL)	www.nrel.gov/lci
CML	www.cmlca.eu
CPM	cpmdatabase.cpm.chalmers.se
E310T	cml.leiden.edu/software/data-e3iot.html
PE International (Gabi)	www.gabi-software.com

studies can be completed using a combination of in-house data and commercial databases to achieve an LCI with suitable data quality.

Once data for each process have been collated, they need to be expressed in a standard format. This usually involves scaling each input, outputs that are not of primary interest and losses to the environment per unit output of interest. Once this has been done, the flows that link each process in the system diagram can be used to calculate the total mass flow per functional unit for the system, the total energy demand and the resulting environmental burdens. It is very important to emphasize at this stage that any calculations should be documented to enable the end user to recreate the calculation if so desired.

4.2.4 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) is the stage of an LCA study when the environmental consequences of a product, process or service are estimated. While many studies stop at the LCI stage, with an estimate of emissions and consumptions, this makes interpretation for both the expert and the general public much more difficult because it is not necessarily clear what the implications of a given emission might be. For example most people know what global warming is, and might be able to interpret global warming potential, but simply knowing a mass of methane emitted by a process may not have very much meaning. In addition, a thorough study might have tens or hundreds of emissions calculated and it is very difficult to make sense of what these all mean. If they are grouped by impact type it becomes much easier to communicate the outcome of the study for any type of audience, and it becomes possible to express the impact per functional unit, which has immediate meaning for producer and consumer alike. The LCIA stage of LCA is rapidly evolving and the focus of much research, but in general impacts are still considered in three categories, resource use or depletion, human health and ecological consequences. This simple classification hides much complexity, including the range of impacts within each (e.g. global warming, acidification, eutrophication), the fact that an impact can be part of a chain of impacts (Finnveden et al., 1992), a given emission can have multiple parallel impacts and that there is great uncertainty as to exactly what the impact of a substance might be, particularly the final consequences. Generalized impacts such as global warming potential are known as mid-point impacts because the final consequences of the emission are not estimated, while end-point impacts attempt to estimate consequences. In the case of climate change this might be loss of life through incidence of skin cancer or starvation due to crop failure (Figure 4.10). Midpoint impacts are a ‘problem oriented approach’ because they model impacts on environmental mechanisms somewhere between the emission and the damage while endpoint impacts are a ‘damage oriented

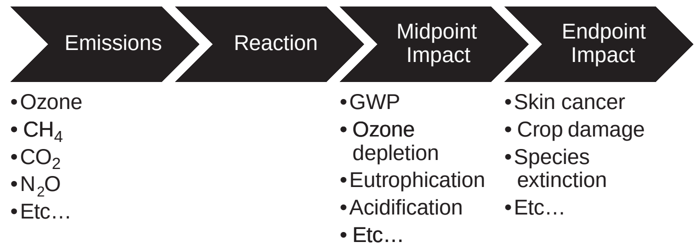

Figure 4.10 The link between emissions, midpoint impacts and endpoint impacts.

approach' because they estimate specific impacts of resource use or depletion, on human health and ecological consequences.

There are seven components in the LCIA stage: (i) selection and definition of impact categories; (ii) classification; (iii) characterization; (iv) normalization; (v) grouping; (vi) weighting; and (vii) evaluating and reporting the LCIA. Normalization, grouping and weighting are optional, but the others are mandatory for ISO standard LCA studies. The selection of impact categories relates to the scope of the study. A single category such as global warming potential might be used to calculate a Carbon Footprint (Flysjö et al., 2011), but as a general rule, a range of categories should be considered, with a focus on those that are likely to be important to facilitate full and proper interpretation. The baseline impact categories are abiotic resource depletion, land use, climate change, stratospheric ozone depletion, human/eco-toxicity, photo-oxidant formation, acidification and eutrophication (Guinée, 2002). As there is now a wide range of methodologies available (Table 4.3), most users will select from the impact categories available in these methods, which are then associated with standard classification and characterization methods.

Within the standard methods the processes of classification and characterization are usually defined. Classification takes a specific emission and links it to a specific impact category. For instance a CO_2 emission is classified as being relevant to global warming potential. Many emissions are relevant to more than one impact category, in which case the method has to account for whether

Table 4.3 Examples of LCIA methodologies that can be used for LCA projects

Method	Source
ReCiPe	www.lcia-recipe.net
BEES	www.nist.gov/el/economics/BEESSoftware.cfm
Eco-indicator 95/99	www.pre-sustainability.com/content/eco-indicator-99
CML 92/2000	www.cml.leiden.edu/research/industrialecology
EDIP 1997/2003	www.man.dtu.dk/English.aspx
EPS 2000	cpmdatabase.cpm.chalmers.se
Impact 2002+	www.sph.umich.edu/riskcenter/jolliet/impact2002+.htm
TRACI	www.epa.gov/nrmrl/std/traci/traci.html
USETox	www.usetox.org

the emission can only have a single impact or whether it applies across multiple activities. The methods define how classification will be handled but for specific projects this detail needs to be noted. Following classification, characterization is used to convert the emission to a standardized impact. The most widely recognized characterization is that used for greenhouse gas emissions for converting methane and nitrous oxide into carbon dioxide equivalents. The choice of method used should be influenced by those most widely used for the specific product, process or service under consideration, but it is worth noting that for some impacts the method makes little difference (e.g. GWP) while for others the difference can be significant (e.g. aquatic ecotoxicity)(Dreyer et al., 2003). Detail of the non-mandatory steps can be found in the ISO documentation (ISO 14044, 2006).

4.2.5 Interpretation

The interpretation phase of LCA is composed of a number of specifically defined components. Firstly we must identify significant issues. This is followed by an evaluation and then we must draw up recommendations and conclusions from the study. Significant issues are those processes, stages or classes of activity that make the largest contributions to the impact of the product, process or service. There are a number of tools that can be used to facilitate identification of significant issues, the simplest of which is graphical representation of data, followed by contribution analysis, dominance analysis and anomaly analysis. Contribution analysis takes the absolute values from the LCIA, expresses each as a percentage of the total impact or the impact for a particular stage and then classifies based on percentage bands. Dominance analysis is a similar approach using statistical methods, while anomaly analysis uses experience, logic or comparison to identify surprising results and those with specific relevance.

The evaluation process examines completeness, sensitivity, uncertainty and consistency. Completeness considers the percentage of the mass and energy of the system captured in the LCI, with a target of at least 90% of each. Sensitivity evaluates the degree to which the end result of the LCIA is dependent of specific values for the activity data describing the system. This is important to identify processes for which the best possible data are required and those that will be sufficient with poorer data. Uncertainty analysis allows interpretation of the results in terms of the probability of the result being correct. Methods such as Monte Carlo analysis can be used (Flysjö et al., 2011). Consistency analysis evaluates all the data sources in terms of the source, technical, geographical and temporal specificity of the data used. Typical questions that should be asked are: (i) are the data quality and any differences within the system definition consistent with the goal and scope; (ii) have regional and temporal issues been dealt with in a consistent manner; (iii) has allocation and the system boundary been applied

consistently; and (iv) have all elements of the impact assessment been applied consistently? Following evaluation it is incumbent on the report's author to highlight clearly any limitation to the study that can be identified.

The final stage of interpretation is to draw conclusions, and as appropriate make recommendations. Conclusions should focus on what the major impacts are, the relative magnitude of the different impacts analyzed, and a statement that the conclusions are consistent with any limitations of the methods and data that have been identified. If recommendations are made, they must reflect a logical and reasonable consequence of the conclusions, an explanation should be provided and they must always relate to the intended application as defined by the goal and scope. If the study is comparative and for a public audience then a full critical analysis must be performed.

4.2.6 Reporting

The report of an LCA study is also subject to ISO standard requirements. The report should be targeted at the audience defined during the goal and scope and should include: (i) administrative information including name and address of LCA practitioner (who conducted the LCA study), the date of the report and other contact information or release information; (ii) definition of Goal and Scope; (iii) the Life Cycle Inventory Analysis (data collection and calculation procedures); (iv) the Life Cycle Impact Assessment (methodology and results of the impact assessment that was performed); (v) the Life Cycle Interpretation including results, assumptions, limitations and data quality assessment; and (vi) Critical Review (internal and external) including name and affiliation of reviewers, independent critical review reports and any responses to recommendations.

4.3 What has LCA revealed about the sustainability of food processing?

LCA has been used to assess the environmental impact of a wide range of food products. There has been a significant focus on the primary production stages, and cradle-to-farm gate studies are common (see for example Yan et al., 2011 for a review of dairy production LCA). There has also been quite a lot of focus on waste management using LCA (e.g. Kim and Kim, 2010). While LCA alone cannot reveal much about the sustainability of the food chain, and the contribution of processing in particular, we can use it to reveal hot-spots, inefficiencies and provide evidence for value choices associated with consumer and producer environmental impact. In the following section we will identify some key lessons learned from LCA studies of animal protein food processing. We could apply the general principles identified just as well to any other food products.

4.3.1 Dairy

The International Dairy Federation (IDF) has estimated that globally, the production stage of milk supply is responsible for about 80% of greenhouse gas emissions and 40% of energy consumption for milk delivered to the consumer (IDF, 2009). For more highly processed dairy products such as yogurt and cheese the contribution of processing is likely to be greater (Xue and Landis, 2010). Grönroos et al. (2006) found that the contribution of processing to energy consumption in Finnish milk supply was dependent on the fertilizer used; under organic production up to 45% of energy can be associated with milk processing because it is not consumed in the manufacture of fertilizer. While single impact LCA studies focusing on Carbon Footprint (Yan et al, 2011) or energy consumption (Grönroos et al., 2006) are common, the real value of LCA lies in being able to compare different impacts and evaluate the value choices that have to be made in order to increase system sustainability. Hospido et al. (2003) found for Spanish milk that processing was responsible for just 20% of global warming potential but up to 65% of ozone depletion potential and 85% of abiotic resource depletion. In this case the major impact was due to packaging, followed by logistics transport and sterilization processing, and these numbers clearly suggest that planning abatement for one impact has potential for both win-win and win-lose outcomes. The major strength of LCA and the use of scenario testing and hot-spot analysis is that it can provide evidence to support better decision making by industry.

There are some common messages we can identify that emerge from dairy LCA studies that include the processing phase between the farm and the consumer. The most important relates to product wastage during processing. The higher the rate of product utilization, and thus the less waste there is, the lower the environmental impact per unit product consumed. This conclusion has been drawn from Norway (Høgaas Eide, 2002), Sweden (Berlin et al., 2008) and UK (Dewick et al., 2007) amongst others. Allied to waste minimization are improvements in transport logistics, including using newer, more efficient vehicles and ecodriving, energy recovery from milk waste, reducing potential packaging waste (i.e. maximizing recyclable packaging) and modernization of processing plants. For instance moving to newer, smaller and more efficient heat exchangers offers great potential for reducing impact at the processing phase (Dewick et al., 2007), and the same could be said for a range of processing equipment where energy consumption can be reduced and fossil fuel displaced with locally produced renewable energy.

The key message that emerges from using 'Life Cycle Thinking' (lct.jrc.ec.europa.eu) in dairy processing is that as environmental thinking (Høgaas Eide, 2002) starts to become part of the day-to-day management of dairy processing plants (along with throughput, legal compliance and food safety) then producers will increasingly think of their product in terms of the whole chain and not just the processing component (Dewick et al., 2007).

4.3.2 Meat

The global impact of meat production has been studied and recently summarized by the UN Food and Agriculture Organization (FAO, 2006). It has been estimated that livestock is responsible for 18% of global warming potential, major impacts on water resources wherever production is concentrated and many other environmental impacts. Our focus of attention when considering the sustainability of meat supply is largely on the production phase (Harris and Narayanaswamy, 2009) with little attention paid to the processing, largely because we perceive it as having relatively minor impacts compared to production.

There are, however, studies that indicate that post-farm activity can be very important in terms of environmental impact. Davis and Sonesson (2008) found that in terms of energy use, it was the steps after the farm that were most important when assessing chicken meals (homemade and semi-processed), and that for greenhouse gases, the farm only accounted for 40 to 50% of emissions. The key steps that were identified for improvement were to reduce food waste (either in the processing plant or the home) and to reduce the transport requirements. An interesting perspective that emerged from the study with regard to processing was the size of portions being prepared and sold. It was suggested that when processing generates large portions the waste will increase and so too the environmental impact. Usva et al. (2009) found that the processing, packaging and delivery phases of the food supply chain for a range of food products in Finland, including meat and chicken was relatively minor compared to the production and home cooking phases so it is clear that there is no simple, one-size-fits-all approach to understanding the role of processing in the sustainability of food supply to consumers.

In a study of red meat production in Australia, Peters et al. (2010) found that the processing phase contributed 10 to 15% to global warming potential, but 50 to 70% of primary energy usage and 70 to 95% of solid waste generation. This indicates that as agricultural production becomes more efficient and abatement measures are put in place, the processing phase will start to appear more important in the global impact of meat supply, and our attention will move from global warming potential to other impacts that will be more significant to processers than producers.

4.3.3 Seafood

The fish harvesting stage of seafood production is generally accepted to be responsible for 70 to 95% of the total impact of fish consumption (Ziegler et al., 2003; Thrane, 2006). Thrane (2006) goes so far as to say that processing is ‘insignificant’ for the flat fish production systems he studied. With such a significant contribution being associated with catching fish rather than processing them, it is reasonable that relatively little attention

has focused on processing. For countries like Spain (second largest canned tuna exporter in the world) there is benefit in LCA studies to evaluate the potential for reducing the impact of such an important food processing industry. A further consideration with respect to seafood is the common practice of processing at sea, where a factory ship accompanies the fishing fleet to complete at least preliminary processing (gutting, filleting, freezing) at sea. Hospido and Tyedmer (2005) found that the marine transport of frozen fish was responsible for over 20% of all impacts from cradle to landing fish in port, but this impact was largely related to transport distance rather than processing activity.

The processing phase of canned tuna supply is responsible for the majority of impacts (eutrophication, global warming, acidification, ozone depletion) (Hospido et al., 2006). Metal packaging, wastewater treatment, additional packaging (for multipacks mainly) and filling with sauces or other liquids were the elements of the processing stage that contributed the most impacts. There is room for improvement identified by LCA in the use of more recycled metal in the packaging or substituting with alternatives such as plastic. If the latter option were followed there might well be consumer backlash as purchasing habits are difficult to change, even for environmental benefit.

Fish products are also produced from freshwater, such as Talapia fillets from Indonesia (Pelletier and Tyedmers, 2010). In this study they found that ocean transport to Europe and the USA made little contribution to the environmental impact because of the major impacts of lake and pond cultivation. It was also noted that if fish meal and oil inclusion rates in the feed were increased these systems would not be net protein producers. This suggests that processing waste in such a system should be minimized to ensure its sustainability. Similar to lake or pond cultivation of fish is the controlled culturing of seafood such as mussels. Iribarren et al. (2010) studied the processing of fresh and canned mussels in Spain, and found that the culturing process was responsible for much of the impact of canned mussels compared to the processing. They concluded this was because the processing was conducted in efficient, optimized processing plants while the supply of mussel cultures was from family run, small-scale businesses that were wasteful and sub-optimal in terms of resource handling. Overall the conclusion was that fresh mussel dispatch was the biggest issue in the system rather than the processing because of the consumption of fresh water and chlorine gas and poor transport logistics. As with meat and dairy production, it is processing waste, excess packaging, inefficient power consumption and poor transport logistics that contribute most to the environmental impact of processing. LCA offers a holistic assessment technique to allow processors to clearly establish the magnitude of their contribution to the sustainability of the food chain and to identify the major contributors to environmental impact that they have to address because they are easy to deal with.

4.3.4 Processed food products, including packaging and storage

The ready meal sector is growing worldwide. It is associated with significant environmental burdens from the raw materials (particularly animal products), the intensive processing required, the amount of waste associated with only supplying 'high quality' food products, a high packaging rate and resulting solid and liquid wastes (Calderón et al., 2010). They found that reducing the meat content of ready meals caused a major reduction in impact, but that transport and logistics were also important. Local supply was a significant benefit for low environmental impact but there was much scope for ecodesign of packaging materials.

Looking at food processing from a different perspective, Milà I Canals et al. (2011) calculated the carbon footprint of the food brand *Knorr* (the largest *Unilever* brand) with a view to allowing the company to find integrated policy options to manage its global impact. This approach has the advantage that it will allow intervention to be optimized across a range of activities rather than to be sub-optimized for a single product line. The major differences between product groups was the ingredient composition and the electricity required for processing so they concluded that recipe specific information is required for product labelling purposes. For most products the processing, manufacture, packaging, waste and logistics were significant contributors collectively to carbon footprint, but across the whole brand they accounted for about a third of the impact, with the consumer accounting for a third and ingredient production the other third. A major conclusion of the study was that for products coming from a complex processing environment such as the *Knorr* brand, there is too much uncertainty to use a product specific carbon label on each item sold and that a brand carbon footprint label would be easier to justify and stand over.

Two of the major impacts of processed food are the packaging, which accompanies more highly processed foods in many markets and the energy demand associated with the processing equipment. Life cycle thinking is leading us to the view that the environmental impact of packaging can be reduced (Peacock et al., 2011) by reducing the amount of materials used (i.e. not having multiple layers of packaging), using materials with low environmental impacts from either renewable sources or those with less end-of-life impact such as biopolymers (Calderón et al., 2010), using recycled materials, particularly glass, metal and paper and encouraging recycling by ensuring packaging is compatible with pre-sorting in the home and the homogeneity requirements of primary processing plants for recycling. Williams and Wikström (2011) however found that in some cases an increase in packaging impact is acceptable if the packaging reduces overall product impact by reducing food waste. Tools such as 'Packaging Impact Quick Evaluation Tool (PIQET)' have been developed around ISO norms for LCA to facilitate specific improvements for processed food packaging (SPA, 2010; Peacock et al., 2011). A study of a range of thermal and packaging options for food storage (Pardo and Zufia, 2012) indicated that modified

atmosphere packaging offered significant advantages for most impact categories provided expected shelf life was <30 days. Interestingly there have been few if any studies that have focused on energy consuming heat exchange in food processing and storages; in most published studies details of this stage of the food chain are not reported in detail.

4.4 Life Cycle Assessment and the Sustainability of Food Processing

The food industry has joined with the European Commission in developing a harmonized framework 'the European Food Sustainable Consumption and Production Round Table' to promote a science-based, coherent approach to sustainable consumption and production in the European food sector (Food SCP, 2010). The need for such activity arose from an industry point-of-view because, rightly or wrongly, it is the processing of food that is perceived with negative connotations by the public despite the fact that many studies stop at the farm gate. The 'manufacture' of food might only constitute 5% of the impact of the supply chain (Peacock et al., 2011), but this remains uncertain because of a lack of published studies. The guiding principles (Table 4.4) of the 'Round Table' are founded in the idea that methodology should be scientifically reliable and consistent, should be easy to understand and not misleading. These principles have meant that there has been a focus on life cycle thinking and a move to looking at the whole supply chain for a product or product groups rather than a specific stage such as food processing.

Table 4.4 Guiding principles of the Food SCP Round Table

Overall	Environmental information communicated along the food chain, including to consumers, shall be scientifically reliable and consistent, understandable and not misleading, so as to support informed choice
Principles for the voluntary environmental assessment of food and drink products	
1	Identify and analyze the environmental aspects at all life-cycle stages
2	Assess the significant potential environmental impacts along the life-cycle
3	Apply recognized scientific methodologies
4	Periodically review and update the environmental assessment
Principles for the voluntary communication of environmental information	
5	Provide information in an easily understandable and comparable way so as to support informed choice
6	Ensure clarity regarding the scope and meaning of environmental information
Principles for both voluntary environmental assessment and communication	
7	Ensure transparency of information and underlying methodologies and assumptions
8	Ensure that all food chain actors can apply the assessment methodology and communication tools without disproportionate burden
9	Support innovation
10	Safeguard the Single Market and international trade

At the same time 'Environmental Product Declarations (EPDs)' (www.environmentalproductdeclarations.com; www.environdec.com) and other eco-labelling have become increasingly common. As noted at the beginning of this chapter, Schau and Fet (2008) reviewed LCA studies that can be used for developing EPDs and noted that there was a focus on simple functional units such as mass, which perhaps hide some of the complexity of the food chain (but are perhaps consistent with the aims of Food SCP). A move to consideration of energy and protein content is desirable to ensure consumers are making valid choices rather than considering a single dimension of the problem (think for example of the consumer choice issues that arose from the move to 'low fat' at the cost of 'high sugar').

In conclusion the question has to be asked, what role does LCA have in assessing and improving the sustainability of food processing? Firstly it has to be said, that in and of itself food processing is not 'sustainable'. A better concept is to consider whether processing is making an active contribution to the sustainability of a food product chain from production to end-of-life post consumption. LCA studies and the methodological philosophy have clearly highlighted the idea that food processing is one small part in a long chain (Figure 4.11) and that analysis of the environmental impacts of processing are critical to ensuring sustainability of quality, safe food supply into the future.

The key messages that emerge from LCA studies are:

- Generation of food waste during processing must be minimized. The greater the waste from processing, the greater the environmental impact per unit product consumed.
- Efforts should be made to divert waste either into energy production (such as by anaerobic digestion) or into alternative valuable product streams.
- Packaged portion sizes should be designed to minimize subsequent waste at the consumer stage. Excessive portion sizes lead to more food waste from the home or restaurants.
- Food packaging should be minimized while serving the required purposes of preservation, protection, safety and promotion of products.
- Packaging should be designed to use and facilitate recycling.
- Transport logistics post-farm should be optimized where at all possible to minimize impact.
- Impacts from energy consuming processes appear to be less important than packaging and logistics, but can still be reduced by modernization to smaller, more efficient processing units that consume less energy during operation.

Figure 4.11 Schematic representation of the food chain and the place of processing within it.

- The quest for simple, easily understood labelling should not be at the expense of meaningful information. The function of food is linked to its ingredients as much as its mass and this should be considered when eco-labelling.

Life cycle thinking and Life Cycle Assessment offer a scientifically valid, somewhat standardized approach to allow food producers, processors and retailers to inform consumers about the environmental impact of their food choices. The knowledge gap that remains for us to fill relates to the question of how to convey the relative environmental impact of products that are of different quality and ingredients. We know from the fall-out from 'low-fat' food labelling that a simple message can be somewhat misleading for consumers, and it is up to the scientific and business communities to find a solution to this problem before the credibility of eco-labelling is undermined. The main strength of LCA probably lies in allowing processors to optimize the food supply chain and specific process, packaging and logistics technologies to make genuine steps towards sustainability, and for this purpose, the simplicity of the consumer message is not required.

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5 Environmental Impact Assessment (EIA)

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5.1 Introduction

The aim of an environmental impact assessment (EIA) is to quantify and understand the effects a new development will have on its surroundings (Payraudeau and van der Werf, 2005). EIAs are most commonly used by local, regional or national authorities and policy makers (Payraudeau and van der Werf, 2005). With an increasing world population and a shift in diets towards animal products (Goodland, 1997; Pimentel, 1994; Kendall and Pimentel, 1994) the cost to the environment needs to be addressed in order to ensure sustainable food production (Wood et al., 2006). Solomon (2007) estimated 21% of all anthropogenic greenhouse gases are from growing, processing, transporting and disposing of food.

To ensure food production sustainability each stage of new food production system should be analysed and their potential environmental impacts must be addressed to reduce pollution to the environment (Kroyer, 1995). The food production sector needs to find ways to reduce pollution from food processing systems by either treating by-products, effluents and wastes or reusing them as valued-added products (Kroyer, 1995). Production scheduling and food processing has previously being based on economy, food safety, utilization of process equipment, labour or traditional methods, however EIA offers food producers a means to compare alternative production scheduling and food

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processing techniques to allow for better use of resources and less pollution (Berlin et al., 2007). EIA of alternative food production systems will allow authorities, policy makers and food producers to determine the most sustainable production systems and allow the consequences of changing production systems to be measured (Milà i Canals et al., 2006).

Food processing sustainability must be viable environmentally, economically and socially. Economic assessment such as cost and benefit along with social assessment such as food security complement the environmental assessment (OECD, 2001; Rasul and Thapa, 2004; Payraudeau et al., 2005). For a new food production system to be environmentally sustainable it must be supported by the natural environment in the long term, including its use of natural resources and its polluting emissions (Payraudeau et al., 2005).

5.2 Defining the objectives

EIA of a new food production system involves firstly defining the objectives such that a sustainable system in environmental, economic and social terms can be achieved (Girardin et al., 2000). Food production systems can contain many stages including agriculture, processing, transportation, storage, distribution and consumer waste. The environmental impact of these stages are referred to as direct impacts, however there can also be indirect or up-stream environmental impacts associated with a production system such as production of capital goods, for example, machinery. These up-stream impacts should be considered when comparing sustainability of proposed production systems (Cuadra and Bjorklund, 2007; Schau and Fet, 2008; Mouron et al., 2006).

5.3 Wastes from food processing

Food production systems commonly emit high levels of the following:

i. organic materials such as proteins, carbohydrates and lipids,
ii. suspended solids,
iii. substances with high biochemical oxygen demand (BOD) or chemical oxygen demand (COD),
iv. nitrogen,
v. suspended oil or grease,

with high variations in pH (Kroyer, 1995).

For example in the meat processing industry wastes can contain high organic loads which have adverse effects on the environment if discharged into water courses without appropriate treatment (Kroyer, 1995). Dart (1974) reported that in the US wastewater from meat and packaging plants was the greatest pollution threat of any food industry. Meat processing plants can have stockyard, slaughterhouse and packaging house wastes, which are all

putrescent and malodorous. The wastewater can contain faeces, urine, blood, grease, washings from carcasses, floor and utensils, undigested food from the paunches of slaughtered animals, wastewater from the cooking, curing and pickling of meat and condensate from rendering of offal, and so on (Kroyer, 1995). In the fish and seafood processing industries wastes include fish flesh, shell, fish bones, cartilage and viscera, and wastewater from washing fish and processing surfaces (Kroyer, 1995). Another example is the fresh and processed fruit and vegetable industries; these can produce wastes from such processes as packaging, canning, freezing and drying operations, as well as washing, peeling, blanching, transport, instrument washing and sterilization. The wastes from this type of food processing have a relatively high BOD (Kroyer, 1995). Finally the dairy industry can produce wastes from the production and distribution of milk and dairy products, such as whey which has a high COD (Kroyer, 1995). When pollutants are emitted as wastewater into a water course it can cause depletion of dissolved oxygen, and production of odours, sludge deposits and unsightly floating scum (Kroyer, 1995). This pollution can then have profound effects on animal and human health.

Packaging is another important factor in food processing which has major implications for the environment. Packaging of food products for distribution to consumers has primary objectives such as protection from physical damage and contaminants, convenience, portion control and so on; however there is a need to reduce its environmental impacts (Brown, 1993). Accompanying an ever increasing amount and range of products available to consumers are increasing amounts of products being sold with packaging; this leads to large amounts of solid waste generation (Pasqualino et al., 2011). Packaging is the second largest component of municipal waste after organic waste and its proportion is increasing (Gómez et al., 2008; Gómez et al., 2009). The environmental impact of a product includes the packaging process as well as the disposal of the packaging materials (Zabaniotou and Kassidi, 2003). Consumers play an important role in management of packaging waste and it is important to help and inform them so that they can correctly identify and classify packaging materials (Pasqualino et al., 2011).

5.4 EIA methodology

The EIA method is based on assessing the impacts of the proposed activity or system by measuring the pollutions associated with the system and sensitivity of the surrounding environment (Payraudeau and van der Werf, 2005). It differs from life cycle analysis in that it usually does not take into account the global impacts of the system (Lenzen et al., 2003). Local impacts such as noise, smell, dust and smoke pollution are prioritized and to a lesser extend regional impacts such as eutrophication and acidification.

The method follows a standardized procedure which allows for comparisons to be made between different proposed systems. Sustainability on

environmental, economic and social levels is taken into account; this allows decision makers to evaluate the impacts of the new system on the surrounding environment and population (Payraudeau and van der Werf, 2005).

The time period over which the EIA is carried out will have effects on the precision of the assessment and the practicality of carrying it out. The area over which the assessment is carried out must be sufficiently precise to allow for accuracy of results (Payraudeau and van der Werf, 2005). It is an important tool in alerting decision makers if a system is sustainable or not in relation to depletion of resources and excess levels of pollution (Duffy, 1992).

The European Union through its environmental policy passed the EIA Directive 85/337/EEC in 1985 (EU Directive, 1985). The principle of the directive is that any planned system that is proposed for development which is likely to have environmental impacts is assessed prior to its approval by the relevant authorities in consultation with the public. The directive defines public and private projects in Annexes I and II of the directive, where the projects listed in Annexe I are considered as having significant environment impact and require an EIA, while for those listed in Annexe II the responsible authorities have to decide whether an EIA is required or not (EU Directive, 1985). The EIA directive of 1985 has been amended three times. In 1997, Directive 97/11/EU brought the EIA directive in line with United Nation Economic Commission for Europe Espoo Convention; it increased the number of types of projects coved under Annexe I and also provided new screening criteria for types of projects listed under Annexe II (EU Directive, 1997). In 2003, Directive 2003/35/EC aligned the provisions for public participation with the Aarhus Convention (EU Directive, 2003). Finally in 2009, Directive 2009/31//EC added projects relating to transport, capture and storage of carbon dioxide to Annexes I and II (EU Directive, 2009). These directives have been codified in 2011 in Directive 2011/92/EC (EU Directive, 2011).

The EU EIA Directive states that ‘member states shall adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue, inter alia, of their nature, size or location are made subject to a requirement for development consent and an assessment with regards to their effects’. It also states that developers are required to supply information which must include ‘at least

- a description of the project comprising information on the site, design and size of the project,
- a description of the measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects,
- the data required to identify and assess the main effects which the project is likely to have on the environment,
- an outline of the main alternatives studied by the developer and an indication of the main reasons for his choice, taking into account the environmental effects,

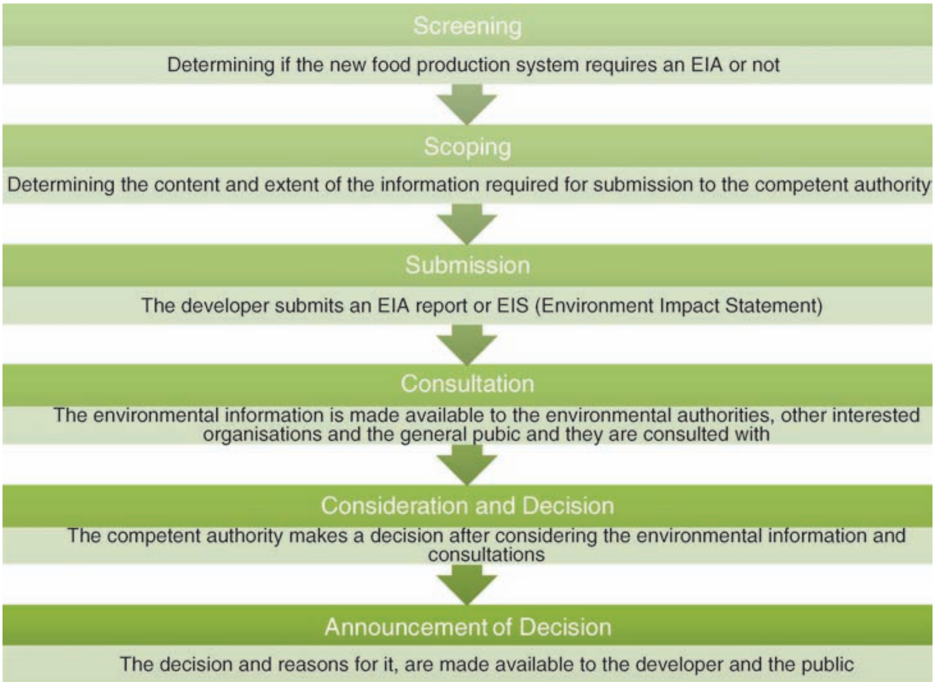

Figure 5.1 Schematic of the European Union (EU) Environmental Impact Assessment (EIA) process.

- a non-technical summary of the information mentioned in the previous indents'.

The European Commission (EC) has published three guidance documents which cover the three specific stages of the EIA process, which are screening (EC, 2001a), scoping (EC, 2001b) and Environment Impact Statement (EIS) review (EC, 2001c). The EU EIA procedure is summarised in Figure 5.1.

Equivalent law in the US which is written in the National Environmental Policy Act (NEPA) requires federal agencies to submit Environmental Assessments (EAs) and EISs, which assess the likelihood of impacts from alternative courses of action. There are similar laws/directives to these enforced by governments globally.

5.5 Environmental indicators

Environmental indicators are the basis for measuring environment impact in relation to the chosen objectives (IISD, 1997). Indicators should be defined before the EIA is carried out. An indicator is a measure of a variable which gives information about a related variable or complex system which is difficult to measure, and allows the user to make decisions (Gras et al., 1989; Mitchell

et al., 1995). Using indicators allows the user to avoid problems of direct measurements such as methodological problems, practical issues, cost and time (Bockstaller and Girardin, 2003). For example global warming potential is an important impact metric, which is strongly linked to fuel consumption and energy use of a system (Blanke and Burdick, 2005; Cerutti et al., 2011).

The Organization of Economic Co-operation and Development (OECD) classify indicators into three categories, that is, pressure, state and response indicators (OECD, 2001). EIA is concerned with pressure and state indicators. Indicators can also be classified as means- or effect-based indicators. Means-based indicators are a measure of the technical means and inputs introduced to the system. Effect-based indicators are reported to be preferred above means-based indicators as they are easier to validate and they represent a more direct measurement of impact (Payraudeau and van der Werf, 2005). Effect-based indicators can be subdivided into emissions- and impact-indicators. Emissions-based indicators are a direct measurement of polluting emissions for the system. Impact-based indicators can be subdivided into midpoint and end-point, depending on at which point in the system they are recorded (Udo de Haes et al., 1999). Midpoint indicators are recorded close to the points of emissions, while endpoint indicators are taken at the point of direct societal concern, that is, damage to the ecosystem. Midpoint indicators are normally used more often than endpoint indicators due to the relative complexity of the latter's measurements (Payraudeau and van der Werf, 2005).

5.6 Functional units

A functional unit for food production is usually a quantity of food produced and commonly is 1 kg of food product. It is a quantified production output unit from the system. When comparing different food products as a protein source, for example, the functional unit can be defined as a unit of protein rather than a unit of the total food. Defining the functional unit of a proposed system has a profound effect on EIA results and it is not always straightforward (Milà i Canals and Clemente Polo, 2003; Cerutti et al., 2011). Cerutti et al. (2011) separated functional groups into the following four categories:

i. mass of product;
ii. land area;
iii. energy use;
iv. economic value.

If the mass-based functional unit is chosen the quality of the product may not be considered (Milà i Canals and Clemente Polo, 2003). The land area functional is neither a direct service nor a production function (Cerutti et al., 2011). The energy-based functional unit refers to the chemical energy in the final food product; while the economic value functional unit is useful for cost

analysis (Mohammadi et al., 2010; Mouron et al., 2006). Therefore defining the functional unit is a user-based decision and should be in line with the specified objectives of the EIA.

5.7 Evaluation of results

EIA results can be presented as impacts in different categories such as global warming, acidification, nitrification, ozone depletion, toxicity, and so on, depending on the end users objectives (Pennington et al., 2004). A total impact indicator can then be calculated by applying weights to each impact category for a given functional unit (Cerutti et al., 2011).

EIA should factor in an evaluation of uncertainty as part of the assessment so that results are properly understood (Payraudeau and van der Werf, 2005). EIA is a highly structured approach to evaluating the potential environment impacts of a system and as such an uncertainty calculation should be an integral part of it (De Jongh, 1988; Steen, 1997). Geneletti (2002) reported however that in reality its inclusion is not common practice. Uncertainty in EIA experiments is a function of spatial and temporal variability of the indicator considered, the analytical protocol and measurement errors (Dubus et al., 2003). The method should be validated with respect to the chosen indicators and their consistency (Payraudeau and van der Werf, 2005).

5.8 Conclusions

All steps in food production systems will have some level of impact on the environment and EIA allows authorities, policy-makers, developers and food producers to make decisions on how best to produce food for an increasing world population without causing depletion of natural resources and severe pollution problems. Food waste often contains valuable components which can be recovered and used in value added products thus reducing the overall by-products, effluents and wastes from the system (Kroyer, 1995).

It is important to include the economic and social objectives when carrying out an EIA to fully examine the sustainability of the new system (Payraudeau and van der Werf, 2005). EIA commonly only factors in local and regional impacts, however, assessment of global impacts, for example, greenhouse effects, are also possible and could be interesting depending on the decision-makers' objectives.

The movement towards the improvement of human health through EIA and sustainability measures outweighs the complexity and costs of the processes involved (Smith and König, 2010). Increasing awareness and motivating authorities, developers, producers and consumers on reaching a sustainable food production system is of key importance to conserving natural resources and minimizing pollution (Kroyer, 1995).

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6
Risk Analysis for a Sustainable Food Chain

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6.1 Introduction

Sustainability in the food chain is a concept which can encompass many different elements, including the availability of a sustainable environment (land, water and food) for future use, without compromising the present requirement, whilst securing available resources. The development of a sustainable food production system necessitates global food security with sustainable food production and consumption, thus ensuring a safe and sustainable supply for the coming decades (DEFRA, 2010). For instance, sustainable agricultural practices can increase the productivity and resilience of future food supplies and increase food security (EU-SCAR, 2010). Technological advancements in food production and processing, in compliance with emerging food safety regulation and food security, is the driving force for sustainable food production, processing and consumption. According to the United Nations Guidelines for consumer protection (1993) '*sustainable consumption includes meeting the needs of present and future generations for goods and services in ways that are economically, socially and environmentally sustainable*'. The Food and Agriculture Organization (FAO) and World Health Organization (WHO, 2007) associated biosecurity with sustainability in order to use safe and reliable technologies that contribute to sustainable agriculture and food production. According to the FAO (2009) World Summit on Food Security, approximately a 70% increase in total food production may be required to feed the projected world population of 9 billion by 2050. Hence,

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sustainability in food production systems is essential to satisfy an ever growing world population. Sustainable food production and supply has become a major challenge for food manufacturers, in particular to meet the increased consumer demand for safe, wholesome and nutritious food. Consumer concern along with emphasis on food chain traceability and transparency has added additional pressure on food producers to ensure food safety. Transparency and food traceability in the food chain are driven by food regulations at both international and national level (Aiking and Boer, 2004). Enforcement of mandatory and optional food safety regulations, for example, Hazard Analysis and Critical Control Points (HACCP), Good Manufacturing Practice (GMP) and Good Hygiene Practice (GHP), can ensure safety and sustainability in food production. Conversely, failure to implement food safety regulations may lead to vulnerability and risks in the food chain which could be a major threat to public health (Aruoma, 2006). A health scare in a food chain may have a direct or indirect negative effect on the global food security, and will envariably have negative economic consequences and in many instances result in expensive product recall and product disposal. Hence, it is in the interests of all stakeholders to ensure safety and security of the food chain, with limited exposure to risks. According to FAO/WHO (1995); risk is termed as '*a function of the probability of an adverse effect and the magnitude of that effect, consequential to a hazard(s) in food*'. Risk analysis is an extension of HACCP, and helps to identify potential hazards in a food production system. In a food chain, the process of risk analysis requires more attention and has become an essential control measure to form the standard norm for both the international and national market.

The transition towards a sustainable food chain may require a systematic approach to impart the scientific knowledge about policies and influences on health and the environment. Risk analysis forms a linkage to integrate safe and sustainable food with various process controls along the entire food supply chain (EU-SCAR, 2010; Knudsen, 2010; Konig et al., 2010). The Codex Alimentarius Commission (CAC, 2003), also recognizes risk analysis as an integral part of the decision-making process of codex for raising social interest and food safety. Risk analysis ensures sustainable food production and consumption without compromising food safety and nutrition of the food. This chapter outlines the various steps and approaches involved in risk analysis including various strategies to ensure the long term sustainability of the food chain.

6.2 Approaches to risk analysis for a sustainable food chain

Risk analysis is widely used in the area of food safety for reducing food risk and the effective reinforcement of food security and safety. It can be

considered an important tool in preventing the likelihood of occurrence of a risk. According to the FAO/WHO (2006), risk analysis is a method that examines potential hazards from an external source, and accounts for potential exposure within the food chain. Generally, consumers are exposed to various risks explicitly like toxic chemicals, smoke or air pollution, harmful bacteria or climatic interference, leading to long term health impacts. In addition, consumers are influenced by varying food choice coupled with price, availability in the market and limited awareness on food safety and nutrition. The likelihood of a risk occurrence in a food production system may be intentional (usually man made) or unintentional (exposure to natural toxins and microorganisms). Potential risks in the food chain pose a threat to human health, either by intentional or accidental contamination of food. Intentional contaminants may be considered a form of food terrorism, having a major impact on social, economic or political stability (WHO, 2002).

In the food chain, while producers strive for 'zero risk' it is unrealistic to state this because it is unattainable due to a high degree of risk uncertainty. Uncertainty in the occurrence of risk poses challenges for the food producer and food safety legislators to eliminate or to reduce food hazards to an acceptable level. For example, WHO (2002) established a provisional tolerable monthly intake (PTMI) of 70 pg WHO-TEQ (toxic equivalent)/kg.bw/month for the food chemical contaminants Polychlorinated dibenzo-dioxins/Polychlorinated dibenzofurans (PCDDs/PCDFs) and dioxin-like polychlorinated biphenyls (DL-PCBs). These tolerable limits ensure a minimum influence on the health of consumers (CAC, 1995) and ensure a minimum level of food safety. Risk analysis can play an important role in establishing these limits.

Risk analysis techniques can be applied to ensure safety and sustainability in the food chain. Risk analysis encompasses three main components, these are: risk assessment, risk management and risk communication as shown in Figure 6.1. These three components are essential to assess the likelihood that a hazard will occur and severity of its occurrence. These components are separate entities but integrate together under a risk analysis project. These elements of risk analysis provide a science-based evaluation of risks associated with foods and help identify the preventative measures which could be used to lower risks. Depending on the complexity of the food chain, risk analysis can be either qualitative, quantitative or both. Risk analysis is a continuous process and frames a strategy, which facilitates the balancing of a sustainable food chain. Risk analysis in the food chain also ensures that food regulations or standards are implemented to maintain a safe and sustainable food supply for both present and the future generations. Risk analysis can be conducted at various stages of a food chain while identifying potential risks requiring attention, thus ensuring public health safety and a better quality of life.

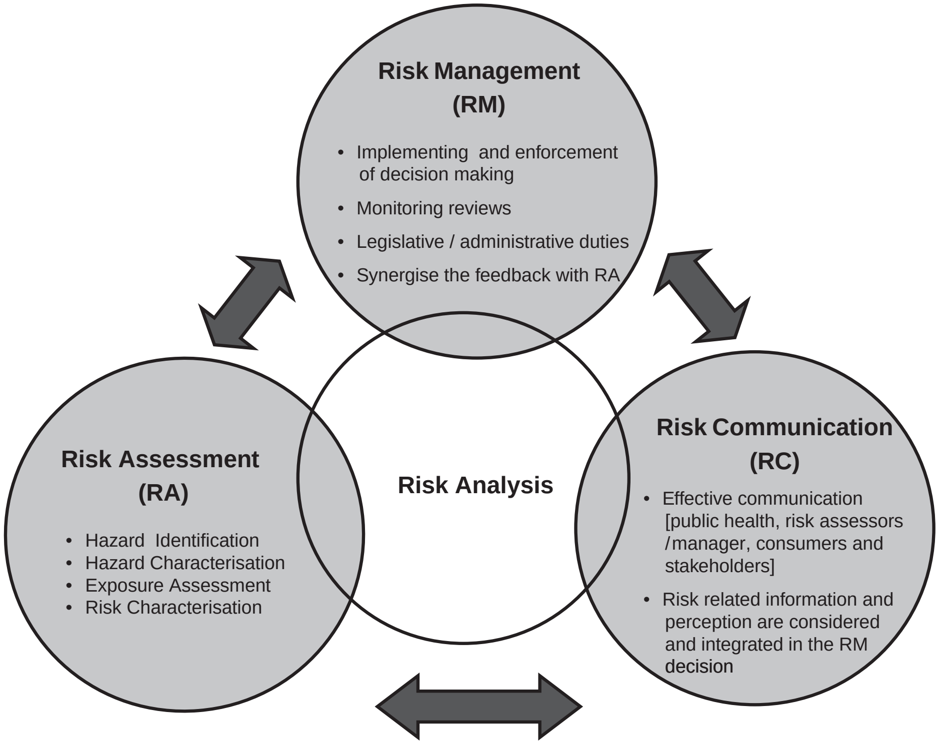

Figure 6.1 Components of risk analysis.

6.3 Risk assessment (RA) strategies in the food chain

Risk assessment is a vital step in risk analysis employed by stakeholders, including food processors, governmental bodies and policy makers to ensure the safety of food. Food safety can be assessed by combining the potential risk/hazard and probability of its occurrence (i.e. chance and frequency of occurring). For an effective assessment, risk assessors are required to understand probability (variability and uncertainty) concepts and should have an ability to develop a robust statistical model. The RA methodology is a harmonized and coherent approach for identifying and characterizing hazards in a food chain. The RA can be carried out at both an international and national level to evaluate the potential adverse health effects in a food control system. Scientific evidence forms the basis for an effective risk assessment while accounting for the inherent uncertainties, assumptions and variability. RA approaches vary depending on the specific application. For example, the U.S. Environmental Protection Agency (US EPA, 1998) defined RA as '*a process that evaluates the probability of occurrence of an adverse health effects as a result of exposure to a*

potential hazard'. Whereas the European Commission (EC) in the year 2000 stated that RA is '*a process of evaluation including the identification of the attendant uncertainties, of the likelihood and severity of an adverse effect(s) occurring to man or the environment following exposure under defined conditions to a risk source(s)*'. Simply, risk assessment is a risk management procedure to analyse and control risk and assess the means to avoid threats or hazards. RA follows a systematic procedure which helps in risk elimination/reduction. It is a dynamic and continuous process that is often used by the risk managers to reduce specific risks and risk factors. As a result, RA plays an important role in regular monitoring and assessment of risk for the continuous surveillance of food production, processing, product storage, shelf-life, marketing and finally consumer exposure assessment. RA techniques can be varied according to the nature of the risk, its probability of occurrence and severity of an adverse health effect. For example, in a microbiological RA, the risk factors involved may be the cause and spreading of a disease which varies with the target microorganism. The assessment generally involves collecting scientific data, organizing and analysing data based on the assumptions and uncertainties. The risk assessor evaluates the nature of hazards, their possible preventive measures, elimination or acceptable levels for a specific risk assessment. Due to the diverse nature of the food chain a multi-disciplinary approach is required, hence the process of risk assessment is generally performed by a team of assessors. The use of a team is a most effective way to synergize knowledge and skills in a relevant area while conducting the assessment and explaining the uncertainty in the outcome and impact of assumptions (FAO, 2005).

RA is collectively supported by the trade associations, food research institutes and scientists, legislation bodies, consumers and academia and so on (FAO/WHO, 2003; Trevisani and Rosmini, 2005). RA acts as a tool to assess the long-term safety/security associated with the food chain and ensures the sustainability of food production systems. There are four essential steps involved in the RA process: 1) hazard identification; 2) hazard characterization; 3) exposure assessment and 4) risk characterization (CAC, 2004).

The estimates of risk and identification of risk factors will consider uncertainties and variability of biological, chemical and physical hazards. Potential hazards occurring in the food chain can be classified as the following:

- Biological hazards (living organisms such as bacteria, viruses, moulds, parasites etc.).
- Chemical hazards (naturally occurring chemicals e.g. glycoalkaloids in potatoes or polyacetylenes in carrots; intentional chemicals e.g. fungicides or insecticides; unintentional chemicals e.g. pesticides, fungicides; others include veterinary residues, non-permissible food additives etc.).
- Physical hazards (foreign materials e.g. stones, metals, wood chips, paper, glass, insects or other filth etc.).

The RA may be based on a systematic qualitative, quantitative or semi qualitative approach to assess the degree of risk to human health (European Food Safety Authority (EFSA), 2006).

6.3.1 Quantitative and qualitative RA in the food chain

Qualitative and quantitative risk evaluation techniques are fundamental methods of RA. Qualitative and quantitative methods can be used depending on the available data, expertise of risk assessor, nature of hazard, scope and purpose of the risk assessment. The qualitative, semi quantitative and/or quantitative evaluation of the health impact of a risk associated with biological, chemical and physical hazard, which may enter in a food chain, can be determined. According to FAO (2005); '*the term qualitative assessment relates to an indication of the attendant uncertainties while the quantitative emphasises reliance on numerical expressions of a risk'*. The RA classifies any risk or a risk causing factor in a food production and processing unit into a qualitative and quantitative assessment.

6.3.1.1 Qualitative RA Qualitative RA is normally used at a preliminary stage to prioritize the risk factors and likelihood of impact of the hazard. This is mostly based on the available scientific information or expert opinions, which assist the risk assessor to understand the nature of the risk and its inherent uncertainties. For instance, qualitative RA is widely used in scrutinizing or rating the quality of imported products (animal or animal product etc.) intended for human consumption. This assessment has the potential to identify the most significant hazard and to facilitate the appropriate analysis. The qualitative RA provides an insight into the risk for the risk manager to make an informed decision. Generally, the qualitative assessment assists the risk assessors in preliminary identification and prioritization of risk (high, medium, low or negligible) to human health which subsequently provides a guide to risk managers so they can implement a control measure (Murchie et al., 2008). For example, Wieland et al. (2011) demonstrated a systematic qualitative RA to assess the impact of existing measures on the spread of African Swine Fever. The authors used risk estimates coupled with several matrices to capture each stage of the risk pathway based on existing data or expert panel opinions. The qualitative assessment procedure may be effective where there is an absence of data or inadequate data (Wieland et al., 2011). Conversely, the quantitative assessments are more suitable for risk assessors where there is availability of good data (availability of numerical estimates) (Wieland et al., 2011). However, several researchers have highlighted the constraints of a full quantitative assessment, mainly pointing to data quality and it being a time-consuming process (Coleman and Marks, 1999; Busschaert et al., 2010; Wieland et al., 2011). In the case where there is limited data, a semi-quantitative assessment

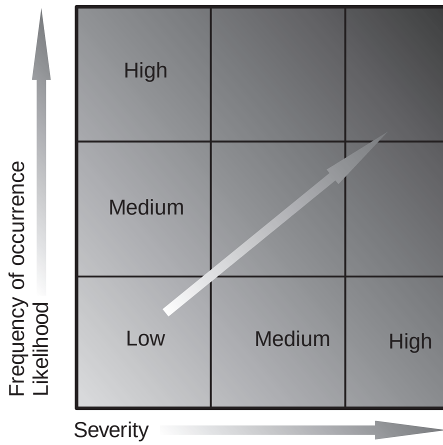

Figure 6.2 Qualitative risk matrix.

may be performed by an assessor. The assessors may apply a maximum likelihood estimation (MLE) as a base for the semi quantitative assessment to deal with the uncertainty and variability in the quantitative assessment. For example, Busschaert et al. (2010) combined quantitative, qualitative and semi-quantitative measurements to study *Listeria monocytogenes* in smoked fish samples with non-detects. Figure 6.2 shows a hypothetical qualitative risk matrix which can be employed to prioritize risks. This type of matrix can be used to classify risk as Low × Low; Low × Medium; Low × High; Medium × Medium; Medium × High; High × Medium; High × High. Similar qualitative risk assessment approaches were employed by the EPA (US EPA, 2009) to classify risk as a major concern, of concern and no concern, based on the combination of low, medium and high descriptors. Such qualitative matrices can also be used to judge the risk as: anticipated, unlikely and extremely unlikely based on frequency and severity.

6.3.1.2 Quantitative RA Quantitative RA is based on numerical data and analysis (deterministic or probabilistic) which can be determined by various statistical techniques. A quantitative assessment follows a stepwise analysis to evaluate the risk associated with a particular food risk. According to Lammerding and Paoli (1997); quantitative RA is a systematic interpretation of the impact of changes in a food chain. Lammerding and Paoli (1997) estimated the probability (including variability and uncertainty) of adverse health effects in association with a particular hazard in a food safety assessment procedure. Within the food chain, the quantitative assessment can be used to obtain a complex and realistic model from farm to fork (Coleman and Marks, 1999). For example, a realistic model can be obtained for microbial growth and

impact of various processing conditions on the likelihood of microbial growth. Such analysis can also quantify the level of chemical hazards in food, estimate the effect of drugs or to assess the impact of a specific component causing the risk (Hoekstra et al., 2008). For example, Vragović et al. (2011) conducted a quantitative RA on two veterinary drug residues (streptomycin and tetracycline) based on the acceptable daily intake (ADI) of milk and meat in Croatia. The same study also estimated human daily intake of streptomycin and tetracycline through the consumption of milk and meat. Vragović et al. (2011) observed a low drug intake and concluded a negligible risk, that is, less than 1% of exceeding the acceptable daily intake. Additionally, these quantifications are usually well represented by stochastic models or predictive modelling. These models aid a risk assessor in capturing variations and uncertainty of a specific hazard in a food chain. Thus, quantitative RA is considered to have an enduring role in gaining the confidence of policy makers for both the national and international food market. In practice, risk assessors have a preference for quantitative RA due to its specificity. In addition, a quantitative RA can provide tangible solutions to specific queries of a risk manager, which may not be as easy with a qualitative RA (FAO/WHO, 1995).

Both qualitative and quantitative RAs are essential to evaluate the probability of a food related risk which consecutively depend on scientific issues relating to food safety and security. To maintain continuing sustainability in the food chain, a risk assessor must continously evaluate a hazard by obtaining information from both qualitative and quantitative sources. A RA team usually compiles all scientific evidence, extrapolated data and other information using databases and software applications to predict several plausible outcomes. Additionally they also develop numerous hypothetical models accounting for the assumptions and uncertainties in extrapolated data and variability in data.

6.3.2 Stages of risk assessment

Risk assessment consists of a number of different stages, which should be considered in all risk assessment studies.

6.3.2.1 Hazard identification (HI) Hazard identification is '*a qualitative process, which identifies hazards in a specific food or in a food group caused by biological, chemical, and physical agents which may have adverse human health effects*' (FAO/WHO, 2007). In a food chain, HI is an essential step involved to elicit the effect, that is, adverse consequences associated with exposure to a specific hazard. HI is a primary screening method which may be a short or long term cell or animal assays screen often used by the risk assessor as an elimination process. Uncertainty and variability in the initial quantitative screening methods also have an impact on the HI due to possible

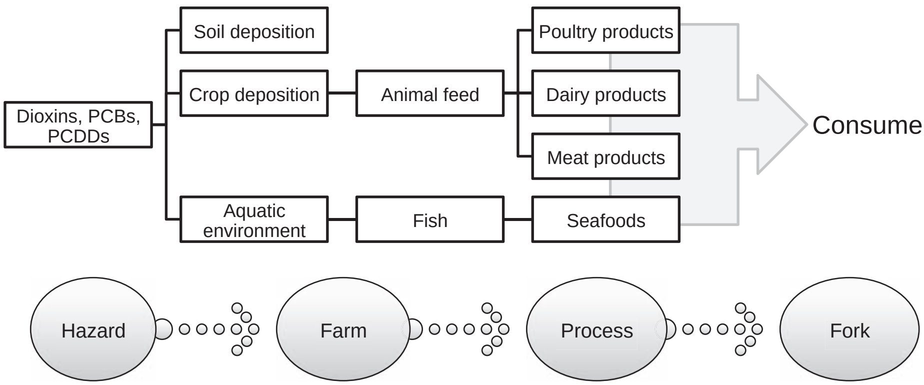

Figure 6.3 Schematic representation of the possible entry route for chemical hazards (dioxins, PCBs and PCDDs) in human food.

misclassification of an agent, performance of chemicals, reliability of screening method or issues in extrapolation of information to predict human hazards (FAO/WHO, 1995). Therefore to identify any food-borne hazard, the HI predominately depends on the relevant data sources from various epidemiological studies, legislation and expert opinion and so on. For instance, to identify microorganisms or microbial toxins in a food chain, relevant data related to sources, mode of transition, incubation period, epidemiology and severity on human and animal health need to be ascertained. HI also identifies chemical and physical hazards which can enter the food chain provided these hazards pose an adverse effect to man (Arcella, 2005). Figure 6.3 shows a diagrammatic representation of a route by which a chemical hazard (e.g. dioxins, PCBs) can enter the human food. These biological, chemical and physical hazards have been encountered in the food chain through identification of contaminants or foreign materials in raw materials, improper handling of food products, visible damage, cross-contamination from poor employee practices or food terrorism (deliberate food tampering).

In a report, FAO (2004) described various identification procedures for illnesses related to seafood for example, Ciguatera fish poisoning associated with the consumption of reef fish. The identification process includes the scrutiny of fish samples from the exporting country to the importing country. As general practice to identify any health hazard, risk assessors use the information based on the clinical studies, epidemiological or national health statistical data to link the hazard and its source to illness. HI procedures may also have limiting factors, including scarcity of available data; expense in gathering data; difficulty involved in information gathering during an outbreak; inability to isolate and characterize new pathogens or unknown organisms (FAO/WHO, 1995).

6.3.2.2 Hazard characterization (HC) Hazard characterization follows the HI stage to evaluate the potential adverse effect of the hazard on human/ animal health. HC evaluates a hazard based on the qualitative or quantitative nature of the hazard and its adverse influence on health. A hazard can be associated with biological, chemical and physical agents in the food chain (FAO/WHO, 1995). The magnitude and probability of a hazards occurrence can be evaluated by considering the dose response relationship. HC also provides a description of a risk to the public health following the exposure assessment. HC characterizes and evaluates each risk specifically for a chemical, physical and biological hazard based on available data. Dose-response modelling can be employed if the data is available. Generally, HC obtains and evaluates data from the epidemiological studies, national health statistics or outbreaks, scientific investigations and information from the HI. The dose-response is usually done based on the mechanism/mode of action of a specific hazard (EC, 2000). HC also characterize both external and internal dose-responses to identify the potential species and/or strain differences either by qualitative and quantitative assessment (Tritscher, 2004). For instance, if any compound has a toxic effect or exerts toxicity, the HC quantitatively form a threshold effect to derive an ADI or tolerable daily intake (TDI) (EFSA, 2006). In toxicological studies, the amount of substance producing an adverse effect on animals and humans are estimated by a threshold level of exposure. For example, no observed adverse effect level (NOAEL), lowest observed adverse effect level (LOAEL) and the bench mark dose (BMD) are used as threshold values for several toxicological studies (Renwick et al., 2003; Oplatowska et al., 2011). Usually a dose-response model depends on the susceptibility and level of a chemical present in the host. The HC also requires information related to a number of cases and illnesses and its exposure routes. In the case of limited data, HC largely depends on the extrapolation studies. Normally the extrapolation studies have greater probability of uncertainty and variability that is, indicating the uncertainty within and between species and variance in the dose levels used for a specific study (WHO, 2009). In addition, uncertainties are common especially in the case of empirical distributions. Other factors are occurrence of variability in bioavailability studies or dosage level. Dose-response models are widely used in HC, though uncertainties in estimates are usually quite high.

Dose-response (D-R) The dose-response assessment is a component of HC, which relates exposure of a particular risk of interest with the concentration. CAC (2003) defined dose-response assessment as '*a technique to determine a relationship between the magnitude of exposure (dose) of a chemical, biological or physical agent and the severity and/or frequency of associated adverse health effects (response)*'. It is a precise quantitative relationship which is usually determined by a dose-response curve drawn for a risk, providing information on the intake range and resulting

consequence (i.e. illness or death) (EFSA, 2006). Normally, risk assessors take into account the factors influencing the dose-response relationships or assessment based on the intensity and likelihood of effect. However, a dose-response assessment is usually performed if the data is extractable (Coleman and Marks, 1999). D-R relationships have been used to indicate the percentage of the population which might be affected when exposed to a particular dose or level of contamination (FAO/WHO, 2003). In a study, Teunis et al. (2010) employed a D-R model for foodborne outbreaks data that is, infection and acute enteric illness associated with *Salmonella*. The authors concluded that *Salmonella* is highly infectious and the risk of illness increases with an increase in dose which is likely to have a higher attack rate. The same authors also noted ID50 (infectious dose of 50% probability) of 7 CFUs for infection and ID50 of 36 CFUs for illness.

6.3.2.3 Exposure assessment (EA) An exposure assessment is a process of estimating the magnitude of exposure to a physical, chemical and biological hazard (e.g. mycotoxins in milk) (Coffey, Cummins and Ward, 2009). EA is a vital component in a risk assessment that evaluates the exposure to the hazard present in the food chain. EA offers information on the possible exposure to a specific hazard for the individual or a group. CAC (2003) defined the EA as *'the qualitative and/or quantitative evaluation of the likely intake of biological, chemical, and physical agents via food as well as exposures from other sources if relevant'*. EA creates estimates of likelihood, magnitude and duration of human exposure to a hazard taking into account the exposure pathway and its route. For chemical exposure, the EA can quantify the chemical intake, exposure pathways and sources of exposure. Likewise, EA estimates the frequency and level of any pathogens present in the food chain which may be responsible for foodborne diseases (FAO, 2003). In the case of an emerging pathogen, the EA considers both route of exposure and duration of contamination (Kleter and Marvin, 2009). The exposure procedure may vary depending on the nature of the hazard or hazard causing agent and the level of hazardous material to which a consumer is exposed. Ideally, the EA estimates the level of hazard (dosage) an individual is exposed to. The exposure can be measured either by a direct (measuring direct contact to an agent causing a risk) or indirect method. The direct method of EA include continuous monitoring of the potential hazard, for example recording the magnitude of nuclear radiation or pollutant on the environment or measuring food safety indicators for human health. Performing a direct exposure may be simple and cost effective however, it is vulnerable to bias factors, which makes it impractical in many instances. Conversely, for indirect EA the concentration of the chemical or additives or pathogen count present in a specific food system are measured and the degree to which an individual is exposed is estimated. In most of the cases, the indirect method is generally used for exposure

assessment. For example, Capleton et al. (2006) observed that indirect human exposure to the residues of veterinary drugs *via* environment poses a risk to human health. The common transit of these residues is through surface waters, aquaculture, and they can enter a food chain *via* animal manure contaminated with veterinary drug residues. In another study, Oplatowska et al. (2011) studied the direct and indirect exposure of triphenylmethanes (a dye used illegally in aquaculture and green paper hand towel production). The triphenylmethanes dyes are known for their carcinogenic properties and Oplatowska et al. (2011) observed that the migration of triphenylmethanes through the skin by using the green paper hand towel within a 5 minute exposure time. The authors also observed that the human exposure to the triphenylmethanes may have a comparable risk factor to that of consuming fish contaminated with triphenylmethanes.

Dietary/indirect EAestimates the amount of hazard intake from a food and food products or any additives. Dietary exposure assessment is conducted by the combination of consumption data of specific food and food products and the concentration of the hazard present in the food. Further, the quality of the dietary exposure assessment in turn depends on the initial screening of specific hazards and its exposure routes within food commodities (Arcella et al., 2005). For example, EFSA (2011) conducted an EA of acrylamide levels in various food stuffs consumed in Europe from 2007 to 2009. EFSA (2011) reported the mean acrylamide exposure for adults (>18 years) was between 0.31 and 1.1 μg/kg bw/day, 0.43 and 1.4 μg/kg bw/day for adolescents (11–17 years) and for children (3–10 years) was between 0.70 and 2.05 μg/kg bw/day. According to the EFSA report the intake of potatoes (fried potato or French fries or potato crisp) was one of the major reasons for the level of acrylamide exposure (Lineback, Coughlin and Stadler, 2011). Generally, risk assessors use the information from EA and transform the information into the form of probabilistic model to generate scenarios and communicate their findings to risk managers.

6.3.2.4 Risk characterization (RCH) Risk characterization integrates the information obtained from HI, HC and EA in order to draft a suitable assessment for risk managers and policy makers to make informed decisions. RCH summarizes the collated information from the above three stages and evaluates the risk estimates taking into account scientific uncertainties. RCH also provides detailed information about the specific risk of a hazard along with its exposure magnitude. The outcome of RCH is the final and key stage of the RA which allows the risk manager to understand the degree of scientific confidence. The RCH is defined as '*the qualitative and/or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health impact in a given population based on hazard identification, hazard characterisation and exposure assessment*' (CAC, 2003). In general, RCH compares the procedures,

relevance of data or analysis used and its outcome and other relevant information to provide a critical view of the RA to the risk manager. Throughout this stage, evidence is gathered to produce a detailed outline of the probability of occurrence and severity of an adverse health effect to obtain a risk estimate. In the case of characterizing any specific risk or an emerging risk, risk managers pin down the critical factors that may influence food safety at each stage of the food chain. Additionally, the RCH clearly identifies data gaps and describes the potential risk estimates considering all assumptions and probabilities (FAO, 2005). Based on risk estimates or risk descriptors, the RCH could quantitatively interpret the level of exposure of a particular risk and its effect on public health. In order to increase the beneficial effects and conversely reduce or eliminate the level of risk, the RCH allows the recommendation of a ADI, TDI and BMD and so on. However, the characterization and selection is usually done at the discretion of the assessor.

In principle, for chemicals HI determines the chemical development, nature and route of the chemical, the dose-response assessment estimates the minimum tolerable dose of the chemical followed by EA, which details the upper and lower level to which consumers are exposed. After considering and examining all the information given by the various stages of RA, the RCH narrates the likelihood of the chemical to cause harm. Likewise, when dealing with an emerging risk the RCH examines several scientific studies and looks at effects on a population or sub-population (e.g. more susceptible population). In the case of evaluating the impact of an emerging risk (e.g. *cronobacter sakazakii*), RCH involves detailed examination of the scientific literature followed by a test on the entire population or on a specific susceptible population. Testing on a susceptible population is cost effective and may reduce the uncertainty of the particular risk but it is time consuming (FAO/WHO, 2003). In some cases where animal testing is performed to evaluate the impact of a risk on humans the extrapolation of animal studies to humans poses a high degree of uncertainty (Renwick et al., 2003). The risk manager uses the data of the RCH, for technological, social and economic concerns to formulate a scientific policy decision. For this reason a good characterization should be clear, articulate major assumptions and uncertainties, identify reasonable alternative interpretations, and separate scientific conclusions from policy judgements (US EPA, 2000).

6.4 Risk management (RM)

Sustainability in the food chain not only requires a RA of potential hazards in the food supply chain but also requires continuous management. RM is a process of continuous monitoring, evaluation and making recommendations to deliver safe and nutritious food products to the consumers. RM is defined

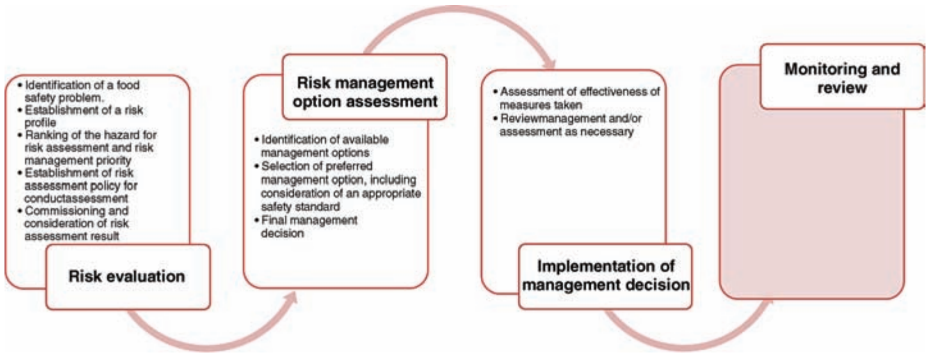

Figure 6.4 Steps in risk management (adapted from FAO/WHO, 1997).

within Codex as '*the process of weighing policy alternatives in the light of the results of risk assessment and, if required, selecting and implementing appropriate control options, including regulatory measures*' (FAO/WHO, 1997). Therefore, RM is a decision-making process which considers risk assessment, technological feasibility, statutory requirements and public concerns for fair trade policy and so on. The RM procedure includes identification of the food safety problem, consideration of the magnitude of the problem and monitoring/surveillance, exposure control, implementing and communicating to the public and stakeholders in the food chain. The preliminary steps in RM as stated by FAO/WHO (1997) are shown in Figure 6.4.

Risk evaluation, risk management option assessment, implementation of management decisions and continuous monitoring are key steps involved in RM (Figure 6.4). Additionally, effective RM can either prevent a risk from occurring or reduce the occurrence of risk. Even if the control measures are developed by the risk managers, the RM team reassess the risk by a mechanism of continuous monitoring and reviewing. Generally, RM is a complex process, which integrates the information from the assessor to make decisions and set up a bench mark dose or acceptable level of risk in a food group. Difficulties remain for risk managers to compare risks from different sources and to prioritize the risks, taking into account the scientific uncertainty and rapidly changing public concerns about food safety, quality and nutrition. The risk of any agent in the food chain varies with the nature, level of exposure and frequency of occurrence on public health. Therefore, RM performs an evaluation process and can recommend control measures at required stages of the food chain and communicate this stringency within national and international food safety risk management (Gorris, 2005). For instance for a microbiological risk, the risk manager evaluates the type of pathogen and its adverse effect on health from the RA and subsequently

develops mitigating strategies to reduce the risk. The decision of a risk manager is very critical and aims to reduce the probability of occurrence of unacceptable risks in the food chain. The RM process also develops risk level based decisions, that is, allowing an acceptable level of risk, while attempting to reduce extreme risks with a high probability of occurrence (Spickett et al., 2011). As discussed earlier, zero risk is an unrealistic notion, which necessitates that risk managers set up an appropriate level of protection (ALOP) articulating a safe exposure level to a hazard in a food chain (CAC, 2004).

The RM stage evaluates on a case by case basis scientific evidence, expert opinion, or based on a specific RCH, and derives accurate and realistic estimations of the risk under scrutiny. In the case of an emerging risk from unknown pathogens or man made hazards (food terrorism) entering into the environment and consequently to the food supply chain the risk manager formulates alternative policies considering the importance of the current issues. Additionally, the risk managers are responsible for implementing strict security from farm to fork to reduce or eliminate health risks. For example, controlling *Campylobacter* in broiler production (i.e. farm) may reduce the probability of bacteria occurring in the chain while also reducing the spread to humans through the consumption of broiler meat (fork). EFSA (2011) reported that the risk of *Campylobacter* in broiler meat to public health may be reduced nearly >50% or >90% by allowing a critical limit of 1000 or 500 CFU/g of neck and breast skin with strict implementation of such limits. Likewise, chemical exposure with specific RCH can be regulated by a risk manager depending upon its severity. For example, to assess the genotoxicity and carcinogenicity of substances present in food and feed largely depends on the type of food and its level of toxicity. In the majority of the toxicological studies, the availability of human data is limited and RA is generally based on the existing scientific *in vitro*, *in vivo* or animal studies and comparisons are made with respect to human health. Such studies are used to draw conclusions and RM decisions are made. EFSA (2005) proposed a margin of exposure (MOE) as a reference point on the dose-response curve (based on animal experiments in the absence of human data) divided by the estimated intake by humans. Based on the MOE, EFSA (2005) recommended a $BMDL_{10}$ (bench mark dose lower confidence limit 10%) corresponding to the 10% tumour incidence in rodents. The risk manager evaluates and reviews the MOE while considering the level of elimination of genotoxic and carcinogenic substances from the food chain. The main principles of food safety risk management are shown in Table 6.1. The RM of a food chain requires decisions that are transparent to stakeholders, food producers, legislators, consumers and regulatory bodies. An effective RM favours integrated decisions at every stage of the food chain, framing policy while evaluating and continuously reviewing the process.

Table 6.1 Main principles of food safety risk management (adapted from FAO/WHO, 1997)

Principles	Role of RM in food safety
1	Risk management should follow a structured approach.
2	Protection of human health should be the primary consideration in risk management decisions.
3	Risk management decisions and practices should be transparent.
4	Determination of risk assessment policy should be included as a specific component of risk management.
5	Risk management should ensure the scientific integrity of the risk assessment process by maintaining the functional separation of risk.
6	Risk management decisions should take into account the uncertainty in the output of the risk assessment.
7	Risk management should include clear, interactive communication with consumers and other interested parties in all aspects of the process.
8	Risk management should be a continuing process that takes into account all newly generated data in the evaluation and review of risk management decisions.

6.5 Risk communication (RC) strategies

Risk communication is an essential element of risk analysis and is an ongoing process, which allows stakeholders to be aware of the risk analysis process right from the start. RC involves stakeholders (mainly consumers, food manufacturers), governments, policy makers, food processors, food scientist, academia, competent authorities at national and international level, risk managers and risk assessors. Ideally, RC integrates the information, facts and opinions related to a risk and facilitates the communication of the decision making process. RC is defined as '*the interactive exchange of information and opinions throughout the risk analysis process concerning risks, risk related factors and risk perception, among risk assessors, risk managers, consumers, industry, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions*' (FAO/WHO, 1997). Many strategies involved in RC can be used in the management of a food related risk ranging from the development of new food policy to sustaining long-term food production, handling and consumption (FAO/WHO, 1998). The communication strategies may differ with a specific risk and when dealing with specific groups of consumers. These strategies can be put in place with regular monitoring by the risk managers. However, these strategies may be altered depending upon the food safety emergency or when communicating about emerging risks to the public and other members of the committee (FAO/WHO, 1998).

The goals of risk communications are as follows (Source: FAO/WHO, 1999):

- Promote awareness and understanding among all participants of the specific issues under consideration during the risk analysis process.

- Promote consistency and transparency in arriving at and implementing risk management decisions.
- Provide a sound basis for understanding the proposed and/or implemented risk management decisions.
- Improve the overall effectiveness and efficiency of the risk analysis process.
- Contribute to the development and delivery of effective information and education programmes, when they are selected as risk management options.
- Foster public trust and confidence in the safety of the food supply.
- Strengthen working relationships and mutual respect among all participants.
- Promote the appropriate involvement of all interested parties in the risk communication process.
- Exchange information on the knowledge, attitudes, values, practices and perceptions of interested parties concerning risks associated with food and related topics.

The process of communication may be performed internally involving risk assessors (and other risk analysis team members) or externally involving stakeholders and other members (FAO, 2005). The internal communication usually occurs between the risk assessor and managers while it is essential for mutual coordination and decision making. For sustainable food production and consumption, both internal and external communications are important to initiate effective public awareness. For example, in any microbial outbreak like campylobacteriosis, a systematic investigation of epidemiological, microbiological and zoonotic information is required. Throughout the investigation effective communication regarding all uncertainties should be fostered between the assessor and the management team for mutual understanding before any decision is made. Conversely for external communication, the decisions (e.g. elimination measures for a microbial hazard) are communicated to the consumers and other stakeholders. Thus, RC emphasizes continuous and transparent exchange of information including scientific opinions. This process of communication ensures logic outcomes and uncertainties are clearly explained to consumers and stakeholders. Another major role of RC is to conduct effective communication especially during any disaster or food crisis (e.g. recent dioxins outbreak in pork), and communicate proper information to the public on food related risk. Timely communication of any risk is an essential task to protect public health. In the case of a foodborne outbreak (e.g. *Listeria monocytogenes* outbreak in ready to eat foods), the risk assessors are required to communicate all possible risk estimates to the risk manager and subsequently to the consumers. The communication should be effective in explaining the severity of disease (listeriosis in case of *Listeria monocytogenes*), its cause, incidence and prevalence in human food. Additionally, RC also communicates the variability which might be involved in the occurrence of

such a disease which may vary from country to country depending on the local eating habits or integrity at the retail level (e.g. temperature control) (WHO/FAO, 2004). Therefore effective communication is vital to increase consumer awareness.

In the food chain, good communication clearly points out the ethical issues related to food safety concerns as stated by the risk manager to the consumers and other stakeholders. Adequate communication also addresses the food safety framework and positive or negative economic or social impacts. For example, the modern application in biotechnology (genetically modified foods) may be important for economic development, however, it may also involve inherent risks (WHO, 2005). The risk manager also evaluates the hazard involved in biotechnological applications and introduces measures to safeguard human health and the environment. Finally, RC also addresses the process of regulatory systems for the consumer and stakeholders and reviews the entire process under the supervision of risk managers. RC allows a final decision to be taken by open dialogue involving various stakeholders and expert committees in a transparent method to ensure food safety from farm to the fork both at a national and international level. The RC ends the entire risk analysis structure, however communication is extended by governments or food safety policy makers who are responsible for enforcing the outcomes.

6.6 Role of risk analysis from farm to fork

Figure 6.5 shows the implementation of the entire process of risk analysis along a food chain from farm to fork. The systematic approach of risk analysis may aid to reduce or eliminate the risk in a food system. Increased complexity, globalization and internationalization of trade are some of the challenges faced in ensuring global food security and sustainability in the food chain (SCAR) (EU -SCAR, 2010).

6.7 Conclusion

Increasing consumer concerns regarding food safety has resulted in demands for healthy and sustainable food production systems. Risk is inherent in the food chain, therefore risk analysis is performed to control or eliminate a hazard in the food chain. Food related risk could be caused either by direct or indirect exposure to foodborne hazards, which may include biological, chemical and physical agents. Risk analysis integrates the three main elements of risk assessment, management and communication which are vital to ensure food safety and sustainability. Sustainability is a key priority area in the food chain which should be based on a farm to fork approach to enable every consumer throughout the world to avail of safe food in a safe environment in conjunction with other social and economic benefits. The governmental role is crucial for addressing the implementation, and assessing implications, of

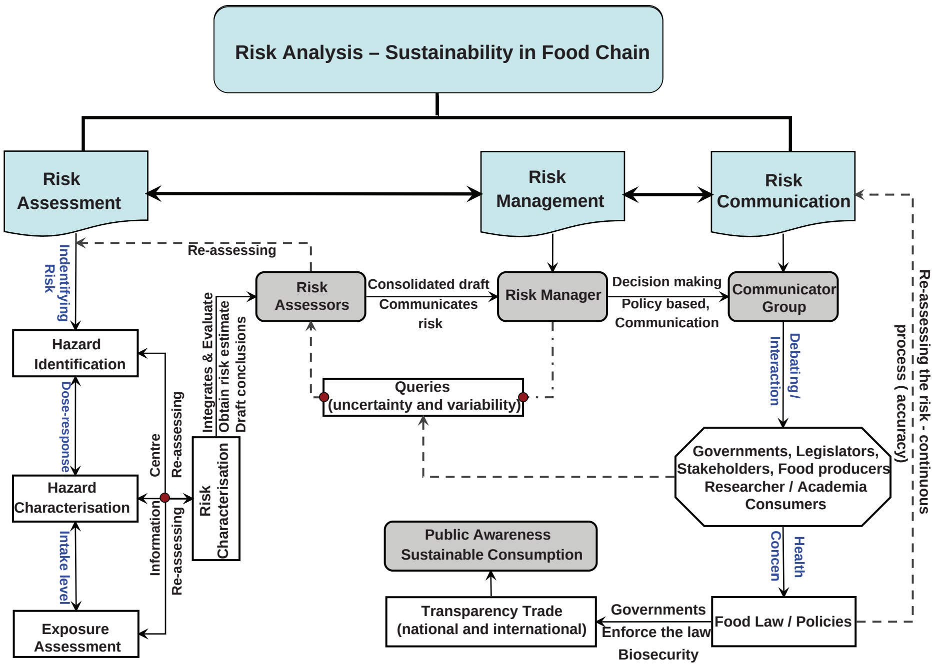

Figure 6.5 Risk analysis for sustainability in the food chain.

controls for any food-borne disease to increase consumer confidence. Additionally, enforcement of food policies, including food security and transparent trade policies, between national and international counterparts will ensure sustainability within the food chain. Several food safety organizations (national and international authorities) have layed down various food policies. National and international food policies will aid in the monitoring and surveillance of potential risks in the food chain with a continuous risk analysis process for developing food control measures to ensure safety and sustainability in the food chain.

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Section 2

Food Processing Applications

7 Dairy Processing

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7.1 Introduction

The world's population has already exceeded 7 billion and is expected to grow to 9 billion by 2050 (United Nations Population Division, 2010). This growing population poses a serious threat to ever-depleting natural resources. Increased usage of resources (food, water and energy) by the soaring population is creating an almost systemic collapse of the ecosystem, together with increased carbon footprints, waste generation and global warming (Preston, 1996). Similar to every industrial sector, 'environmental sustainability' and 'go green' have been trends in food industries for the past few years.

Stakeholders in food industries, including producers, manufacturers, wholesalers and retailers, are leading pioneering activities to reduce greenhouse gas emissions during the food miles covered within the entire food product cycle, from procurement of the raw materials until the final product reaches the consumer (Engelhaupt, 2008). Recently, we analysed food-industry-linked environmental impacts in general and the corporate social responsibilities of dealing with carbon footprints by reviewing relevant case studies from leading food companies and retailers (Sarkar et al., 2011). However, it is obvious that food processing varies enormously, generating different ranges of products from milk, meat, sea food, cereals, fruits, vegetables and so on. Furthermore, these processing sectors create different kinds and various degrees of environmental footprints. For example, empirically, cereal industries might generate more solid waste than dairy industries, when the initial raw material (cereals versus milk) is considered.

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Hence, an understanding of specific stream of food processing is vital for developing relevant strategies to reduce greenhouse gas emissions or efficiently manage the initial natural resource inputs.

Compared with many other food sectors, dairy industries have contributed substantially to significant ecological footprints, by degrading natural resources (e.g. consuming energy and water) and triggering greenhouse gas emissions during the food miles covered within the entire cycle from the production of feed for dairy cows to processing, packaging and distribution of milk and/or milk products. For instance, the associated greenhouse gas emission [carbon dioxide (CO_2)] is 5.9 kg CO_2 equivalents/kg for cheese, compared with 0.17 kg CO_2 equivalents/kg for peanut butter (Kramer et al., 1999). In this chapter, we specifically focus on aspects of dairy processing from the standpoint of environmental sustainability.

Since the nineteenth century, dairy industries have shown genuine leadership in promoting sustainable initiatives, particularly in reducing energy usage. The first question we need to ask ourselves is: Why has this sector attempted to minimize resource usage in the past? In an attempt to answer this question, the first section of this chapter provides a short introduction to the fundamental drivers of previous and current sustainable initiatives in dairy industries for the efficient conversion of milk into dairy products.

The main body of the chapter includes a detailed discussion on the sustainability initiatives taken by dairy industries at each step of the unit operations used in manufacturing various dairy product categories. Broadly, these initiatives include saving energy during thermal processing operations or refrigeration, reusing or recycling water, minimizing waste generation, effectively managing resources by reclaiming and utilizing by-product streams, and lowering carbon footprints during overall processing, packaging and transportation. However, dairy industries face enormous challenges if they are to satisfy the demands of future environmentally conscious consumers and the global targets for carbon footprints. In this chapter, we discuss various aspects of dairy processing, with particular focus on fluid milk, concentrated and dried milks, fermented dairy products (cheese and yoghurt), fat-rich dairy products (cream and butter) and by-products, in the context of creating environmental issues and consequently traditional, current and future practices for manufacture in an environmentally friendly manner. We also describe the sustainability issues and practices in the context of utilities, such as energy and water usage. Furthermore, sections on packaging and transportation are included, to give an overview of environmental issues and best practices adopted in the entire dairy processing value chain from production to consumption.

Finally, this chapter attempts to highlight some key future strategies for efficient manufacture that might be adopted by dairy industries in order to 'go greener' and to create environmentally sustainable dairy products.

7.2 Drivers for sustainability in the dairy processing sector

Numerous attempts have been made to define 'sustainable development' or 'sustainability'. These words have been used in different contexts from finance to environment. For the scope of this chapter, discussion is restricted to the context of the environment. The definitions of sustainability in the literature can be broadly classified into two major groups: those based on its essence and those based on outcomes. The term sustainability is derived from the Latin word *sustinere*, which means 'to hold'. The most widely accepted definition of sustainable development was given by the United Nation's Brundtland Commission on environment and development in 1987 and is development that 'meets the needs of the present without compromising the ability of future generations to meet their own needs'.

In the context of dairy industries, to ensure long term environmental sustainability, that is, to meet the needs of dairy products for current and future generations, the drivers for sustainability must be understood. Gaining insights into the drivers for sustainability in dairy industries would help to understand the historical approaches and to design future strategies to improve the performance of dairy processes in such a way that the environmental footprints are minimal at each processing step, while satisfying the preferences of consumers. In this regard, we identify three key drivers, which are discussed in the following subsections.

7.2.1 Economic returns

Traditionally, technological advances in minimizing footprints were primarily associated with economic benefits. To improve bottom-line savings, dairy product manufacturers have historically looked at ways to reduce operational costs by minimizing energy usage. For example, high temperature short time (HTST) pasteurizers (basically, plate heat exchangers) are generally used to produce pasteurized fluid milk; they typically consist of a regeneration section to optimize the heat recovery between a cold raw product and the same hot pasteurized product. Basically, by preheating the incoming raw milk with the outgoing hot pasteurized milk without using an additional heating medium, regenerative heating systems can achieve significant economic savings that are approximately 90% or even more of the energy savings (discussed in Section 6.3.1) (Sarkar et al., 2011).

The primary financial driver for many dairy industries has also led to the recovery of by-products (e.g. whey, skimmed milk and buttermilk) (Section 5.3.5) from waste streams to create new main product streams, minimizing the drainage of effluent and improving the efficiency of operations. The core concept of sustainability stresses the need to care for the future by improving efficiency, reducing energy usage and minimizing waste. Hence, even today,

dairy industries take significant environmental initiatives by increasing their efficiency of production and reducing resource usage to remain competitive and to operate profitably, thereby also contributing to ecological sustainability. Thus, the environmentally efficient production of dairy products is more a result of strong business impetus rather than ecological sustainability in the first place.

7.2.2 Stricter regulations

Sustainability in dairy industries is also largely driven by stricter local, as well as global, regulations. Because of stricter government regulations, dairy industries are pushed to reduce both the volume and the polluting load (biochemical oxygen demand) of their wastewater (Sage et al., 2008). For example, in the European Union, dairy wastewaters require specialized treatments to meet effluent discharge standards (Water Framework Directive 2000/60/EC). Also, because of stringent environmental regulations, dairy industries are gradually shifting from using coal as a fuel source to minimize CO_2 emissions (Ramírez et al., 2006). In addition, legislation is forcing dairy industries to take environmentally sustainable actions, not only by penalizing excessive use of utility services (e.g. energy and water) but also by imposing tough penalties such as cancelling licences for non-conformance to standards for emissions and effluents. Furthermore, in some countries, local governments have introduced provisions to reward dairy processing plants (e.g. the U.S. Dairy Export Council Award for Outstanding Dairy Processing & Manufacturing Sustainability) that are adopting proactive approaches to ensure that their operations pose minimal environmental threats. Interestingly, some local governments are also introducing 'climate labelling'. For example, the Swedish National Food Administration, in association with the Swedish Environmental Protection Agency, has introduced climate-certified labelling systems for various food products, including dairy products, to enable consumers to choose products according to their minimal environmental impacts; the government will soon make 'climate declaration' labelling mandatory on dairy product packages, similar to nutrition labelling.

With the introduction of quality management systems such as ISO 14000, products must comply with ecological requirements to be considered to be quality products in the broad sense (Stauffer, 1997). ISO 14041 (Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis) describes special requirements and guidelines for the preparation, conduct and critical review of the life cycle inventory analysis of food products (Boudouropoulos and Arvanitoyannis, 1998). The introduction of environmental management systems, which consider sustainability through meticulous analysis of environmental impacts, also puts pressure on dairy industries to limit their greenhouse gas emissions (Begley, 1996). The steadily increasing number of regulatory requirements in environmental sustainability has

also motivated companies to develop their own environmental management strategies. Specialized management systems, such as Six Sigma and Total Quality Management, are self-regulated drivers that are used in many dairy industries to devise a top-to-bottom strategy for monitoring efficient utilization of resources and minimizing waste generation at each step of operations in real time.

7.2.3 Green consumers

Governments and non-governmental eco-friendly organizations in the USA and developed countries in Europe are actively involved in creating a significant increase in the environmental awareness of consumers. With changing times, environmentally conscious or 'green' consumers are apparently connecting with products or brands that are associated with minimal environmental impacts (Mackenzie, 1990). Interestingly, dairy industries that demonstrate their commitment to the environment are considered to be more responsible and their products are preferred over corresponding products of their competitors because of the increasing awareness of green consumers. Hence, increasing numbers of dairy industries are introducing environmental sustainability and an eco-friendly supply chain into their short and long term goals in order to gain consumer satisfaction and have competitive advantage. Recently, one of the world's largest retailers, Walmart, has proposed a Sustainability Index, which will push Walmart's suppliers to adopt stricter environmental standards and provide consumers with specific sustainability information on their product labels. This kind of driver clearly shows that the greener aspects of communication are influencing the purchasing decisions of consumers and are gradually obliging industries to make strategies for developing products with minimal environmental impact.

In summary, it is clear that environmental pressures from both governments and consumers have forced dairy industries to review the way in which they utilize their water, energy and natural resources (mainly milk). However, ecological sustainability must ensure economic benefits (such as lower operating costs by decreased energy usage) for the dairy industry stakeholders in terms of the efficient conversion of raw milk into dairy products and to gain financial returns. Different processing operations are described from an environmental standpoint in the next section, to review the environmental initiatives adopted by dairy industries.

7.3 Sustainability initiatives in dairy processing operations

Dairy industries use milk to produce a broad range of finished processed products. From an environmental point of view, dairy industries produce substantial environmental footprints at each step in the value chain, that is,

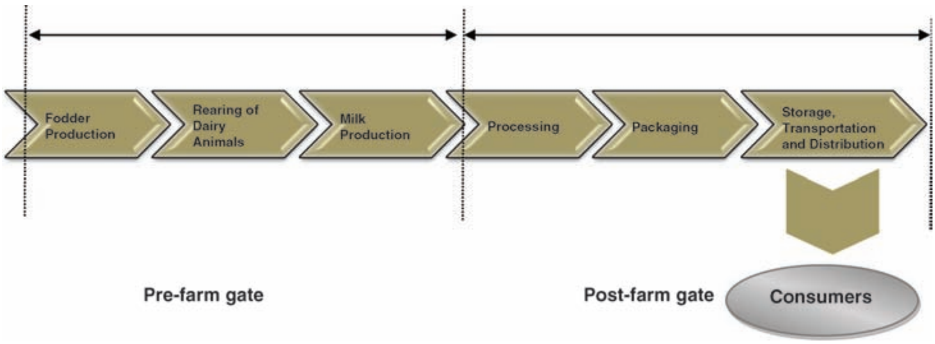

Figure 7.1 Schematic diagram showing milk processing, from the farm until the product reaches the consumer.

fodder production, rearing of dairy animals, milk production, processing, packaging, distribution, storage and retail, until the product reaches the consumer, as shown in Figure 7.1. Empirically, we can divide the value chain into pre-farm gate and post-farm gate. It must be noted that, when the entire life cycle of packaged fluid milk, that is, milk production, dairy unit operations, packaging and distribution, until it reaches the consumer is considered, the greenhouse gas emissions during agricultural production seem to be significantly higher than those for other aspects of the value chain (Berlin, 2002; Eide, 2002; Milani et al., 2011). For instance, the total emission of the entire milk chain is reported to be about 0.65 kg CO_2 equivalents/kg milk, of which the pre-farm gate operations contribute about 0.4 kg CO_2 equivalents/kg milk (Eide, 2002). This clearly indicates that the environmental impact on air and water associated with dairy farming is extremely important and requires considerable attention in the minimization of environmental impacts. However, in the context of this book, we limit our scope to dairy operations only, that is, post-farm gate.

Dairy industries manufacture a wide range of products, such as fluid milk, cream, milk powders, concentrated milks and fermented dairy products (such as cheese and yoghurt), as shown in Figure 7.2. As a by-product of mainstream processing, they also generate skimmed milk, casein and whey, which are further leveraged into dairy ingredients such as skimmed milk powder, whey protein concentrate/isolate and lactose. Although the products differ in their manufacturing technologies, the main unit operations usually include thermal processing, refrigeration and mechanical shearing operations (mixing and homogenization), which involve significant energy usage and generate environmental footprints. In terms of resources, inputs usually include raw milk, water, other ingredients (sugar, flavours, bacterial cultures, emulsifiers, stabilizers, preservatives etc.), electricity, fuel, cleaning chemicals and packaging materials. The unit operations and the

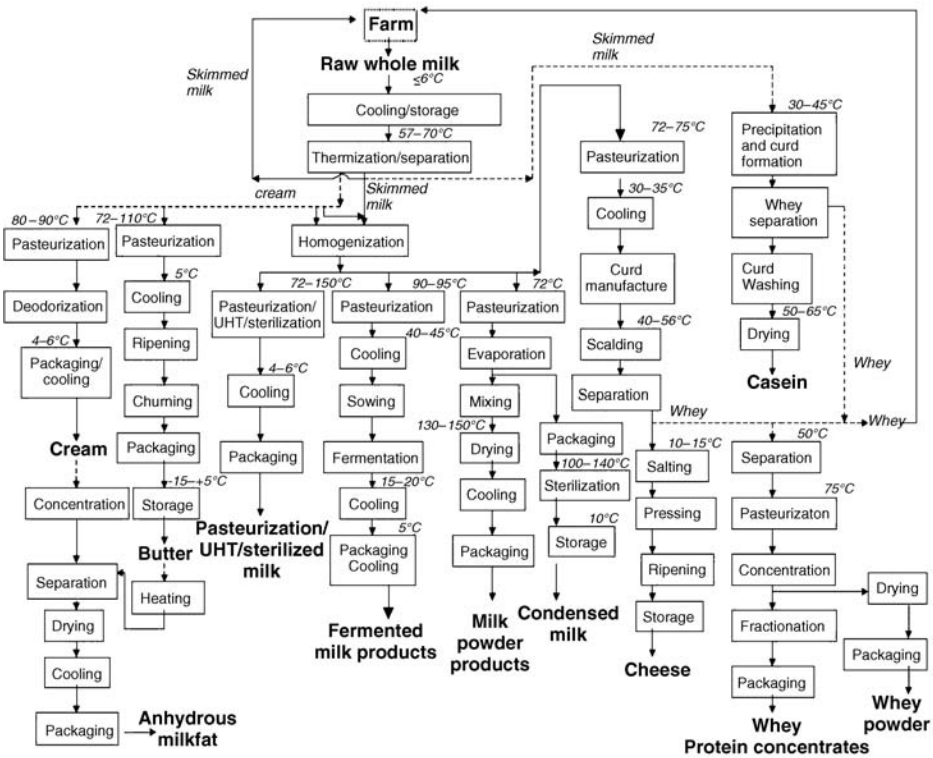

Figure 7.2 Flow chart of dairy processing operations (Ramírez et al., 2006, reproduced with permission of Elsevier).

manufacture of dairy products have been extensively studied and are well documented in textbooks.

Hence, in the following subsections, milk products, such as fluid milk, concentrated and dried milks, fermented dairy products (cheese and yoghurt), fat-rich dairy products (cream and butter) and dairy by-products (whey, skimmed milk and buttermilk), and their processing are briefly discussed with particular reference to current sustainable operations and the potential for future improvements to minimize environmental impacts. The processing of ultra high temperature (UHT)-treated milk and ice cream is also briefly covered from a sustainability viewpoint in sections describing ecological initiatives in packaging (Sections 6.3.1 and 6.4) and utilities (Section 6.5.2) respectively. As dairy products are highly diverse and vary across countries, data on sustainable practices that are adopted by small scale dairies for the manufacture of traditional local dairy products are often unavailable and hence are not discussed in this chapter. For detail on dairy processing operations, readers may refer to De (1985), Robinson (1994) and Bylund (1995).

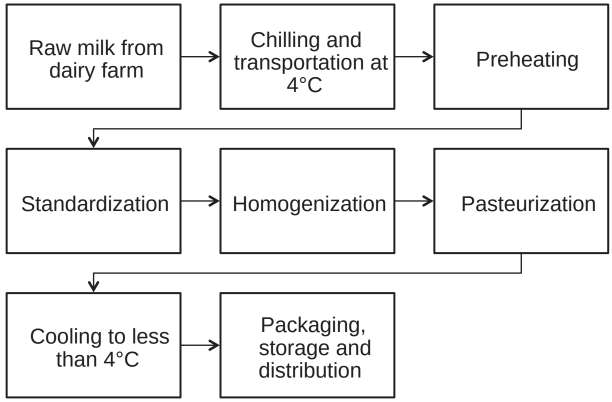

Figure 7.3 Flow chart of the operations in the manufacture of fluid milk.

7.3.1 Fluid milk

Fluid milk is one of the most important products that is produced at any dairy factory. Because it is extremely perishable, it is highly susceptible to microbial spoilage. To minimize the growth of spoilage bacteria, milk is always held chilled at temperatures below 4 °C. Depending on the quantity, milk is usually collected by milk tankers or in cans and is brought to the dairy factory. As shown in Figure 7.3, the chilled raw milk is stored initially in bulk coolers on the production farms and is transported to the dairy factory in insulated tankers (temperatures of less than 4 °C), which utilizes a significant amount of refrigeration.

After an initial preheating and standardization to the desired fat and milk solids-not-fat contents, the milk is homogenized. Homogenization is an important and necessary pre-treatment for the processing of milk, because it prevents creaming. Rather than the widely known high pressure homogenization techniques, novel technologies such as ultrasound may be used for emulsification to create stable milk, avoiding gravity separation (Wu et al., 2000; Augustin et al., 2012). It has recently been reported that ultrasound can create nanoemulsions and is 18 times more energy efficient than other emulsion generation techniques such as microfluidization (Tang et al., 2012). The ability of high frequency ultrasound to prevent creaming may provide new opportunities to lower the energy demand for the homogenization of milk.

From an environmental viewpoint, the most important unit operation in the production of fluid milk is pasteurization, which is the most common thermal treatment in a dairy factory. It involves raising milk to a specific temperature and holding it at that temperature for sufficient time to destroy any pathogenic bacteria that are present in the milk and to render it safe for human consumption. Small dairy units generally use a batch process for

pasteurization. A batch pasteurizer is a jacketed vessel with an agitator to achieve high heat transfer coefficients. The product in the vessel is generally heated at or above a set temperature (e.g. 63 °C for fluid milk) with the help of a heating medium in the jacket (usually hot water) and is held at the pasteurization temperature for a set time of 30 minutes. At the end of the holding period, the product is cooled to ambient temperatures with water and then with chilled water.

The batch process has several disadvantages, such as requirement of headspace, large volumes of heating and cooling media, long residence times involving huge energy consumption and losses in the nutritional quality of the product. Large dairy factories use high temperature short time (HTST) pasteurizers, which require a temperature–time combination of 72 °C/15 s for fluid milk. These types of pasteurizer are plate heat exchangers, with the product and the heating or cooling medium flowing in channels in between the plates, which serve as heat transfer surfaces. The regeneration section of an HTST pasteurizer is a classic example of a traditional sustainable approach adopted by dairy industries to conserve energy. In the regeneration section, the outgoing heated milk is cooled with the help of the incoming raw milk. Thus, the outgoing milk is cooled sufficiently by the incoming raw milk before being chilled to less than 4 °C by chilled water. The amount of heat taken up by the raw milk in turn reduces the load on the heating system by reducing the total amount of heat required to bring the raw milk to pasteurization temperature.

Using regeneration, it is possible to recover more than 90% of the heat, resulting in enormous energy savings, resulting in minimizing environmental impacts. The efficiency of regeneration can be calculated using the following equation (Robinson, 1994).

$$Regeneration\ efficiency = \frac{Amount\ of\ heat\ supplied\ by\ regeneration}{Total\ heat\ load\ assuming\ no\ regeneration} \times 100 \tag{7.1}$$

Even UHT treatment of milk, in which the milk is heated at around 135–150 °C for a few seconds followed by integration with aseptic packaging in sterile containers, which allows milk to be stored at ambient temperature for over 6 months (Burton, 1977; Deeth and Datta, 2002), uses heat regeneration. In this way, indirect heating systems result in 80–95% energy recovery. Moreover, because of the shelf stability of the processed UHT-treated products, this process eliminates huge amounts of energy usage in terms of refrigeration during transportation, distribution and storage. However, it should be noted that, in terms of their heat treatment requirements, UHT-treated products consume far more energy than pasteurized fluid milk (Hvid, 1992; Ramírez et al., 2006).

Generally, high regeneration efficiency is desirable. Dairy factories can further improve the regeneration efficiency by increasing the number of plates in the regeneration section and selecting a suitable plate design for maximum energy utilization. Furthermore, periodic cleaning in place (CIP) of the heat transfer surface on the milk side to remove scale formed by thermal denaturation of the whey proteins can help to improve the efficiency of heat transfer and thus to minimize energy usage. Dairy factories can adopt optimum temperatures and concentrations for the cleaning agents to optimize operations between two CIP cycles to improve the efficiency of operations.

Using a life cycle assessment (LCA) approach, Stefanis et al. (1997) evaluated the environmental impact of dairy processing and indicated that cleaning had a significant effect on energy usage and waste generation. Therefore, along with energy usage in thermal treatment, the increased cleaning chemicals that are needed to clean the fouled heat exchangers and the remaining plant processing equipment also affect environmental footprints. Improvements in cleaning heat exchangers would provide substantial energy savings, optimized water usage and finally a reduction in the environmental impact (Jun and Puri, 2005; Christian and Fryer, 2006).

Another area that represents a huge opportunity for energy conservation is the energy loss from non-insulated pipelines. Energy lost can be in terms of heat gain or loss from the fluid milk. The total length of pipelines in a dairy factory, from reception of the milk to packaging machines, can be up to several hundred metres. These pipelines include lines used to transfer raw milk to storage tanks, and transfer lines to and from the pasteurizer, homogenizer and packaging machines. Moreover, the holding tubes of the pasteurizer serve as one of the major sources of heat loss because they contain the product at its maximum temperature in the pasteurization cycle. In large processing plants, the holding tubes can often be up to several metres in length and the normal daily operation of the milk pasteurizer can be in excess of 16 h. Furthermore, a large factory with a capacity of several million litres will have more than one pasteurizer. Thus, the cumulative heat loss from the holding tubes will be magnified greatly with the scale of the dairy operation. The losses from transfer lines and holding tubes can be reduced by using insulation of appropriate thickness. Thus, insulated pipelines might provide energy savings and might thereby result in reducing environmental footprints.

In cases where insulation of the transfer lines is not possible, the storage tank areas (generally maintained at 4 °C) could be separated from the product processing area to avoid possible heat gain from the latter. As well as insulating the holding tubes, the heat that radiates from the tubes can be recovered by housing the holding tubes in a separate insulated room in the production area. This will lead to the dissipation of a considerable amount of heat energy, which in turn can be reused for other dairy

operations such as melting butter, melting chocolate or coatings for dipping ice cream or even incubating yoghurt packs. The environmental impacts related to cooling and refrigeration are also enormous and are discussed in Section 6.5.2.

7.3.2 Concentrated and dried milks

Evaporated milk or unsweetened condensed milk involves a process of increasing the total solids of the milk or milk product by removing water. This is done for several reasons, such as reducing the bulk for storage and transportation, extending the shelf life of products, manufacturing different dairy products and pre-processing before drying. In dairy industries, a concentration process is generally employed for whole milk, skimmed milk, buttermilk, whey and so on (Kessler, 2002). Traditionally, open pan boiling of milk was used for concentration. In the open pan method, the milk is concentrated by boiling at atmospheric pressure using an open flame or by steam in a jacketed kettle. The sides of the kettle are scraped continuously, manually or mechanically, until the desired consistency of the product is reached. This process is enormously energy intensive, because the boiling point of milk is higher at atmospheric pressure than under vacuum, and also significantly affects the nutritional and sensory properties of the product. Moreover, there are no provisions for reclaiming the vapours that leave the product. Hence, as expected, such a concentration process is not environmentally friendly.

The most commonly employed method of concentrating milk in dairy factories is to evaporate water from the milk under vacuum. Boiling under vacuum prevents deterioration in the nutritional and sensory properties by reducing the boiling point of water and ensuring its removal at lower temperature. This reduces the heat energy required to remove water from the feed and provides substantial energy savings. Large dairy factories with continuous operations may have equipment known as evaporators, which are large stainless steel shell and tube type heat exchangers. The tubes contain the product to be concentrated and the outer shell contains the heating medium. Evaporators are classified mainly on the basis of the direction of product flow in the tubes, for example, falling film or rising film, and the number of evaporators, for example, single effect or multiple effects.

Kessler (2002) discusses the different types of evaporator and their advantages and limitations. One or more evaporators can be used in series by adjusting the boiling points in successive evaporators. This enables the latent heat of the vapour escaping from the previous evaporator to be used as the heating medium in the next evaporator, which is accomplished by adjusting the vacuum. Each evaporator in such a multi-evaporator condensing system is referred to as an effect. Theoretically, as each effect reduces the heat requirement to about 33%, the total heat requirement for evaporation per

kilogram of water removal can be reduced significantly by increasing the number of effects (Bylund, 1995; Kessler, 2002).

The vapour from the preceding effect can be further recompressed for greater steam economy by thermal vapour recompression or mechanical vapour recompression and can then be used to heat the milk in the next effect of the evaporator, which may be operated at a lower pressure and a lower temperature than the preceding effect. Thus, using multiple effect evaporators together with recompression can contribute to the operational and energy efficiency. Concentration using membrane filtration techniques, such as ultrafiltration, microfiltration, nanofiltration and reverse osmosis, which require significantly less energy than evaporation, can also be adopted (Hvid, 1992). Such a technique can be a suitable option when concentrating milk up to 12–20% solids (Ramirez et al., 2006). Thus, the evaporation of milk is a sophisticated state-of-the-art example of energy management as practised traditionally in dairy industries.

Although, multi-effect evaporators and vapour recompression are significant steps in energy conservation, there is still significant potential for improving efficiencies. Because of the large size of each effect in an evaporator, a significant amount of heat is lost from its surface. Insulation of the surface could be a means of reducing the amount of heat loss as a result of radiation from the hot surfaces. Furthermore, the condensate water can be used for CIP or as feedwater for the heating system, and this is currently practised in dairy industries. Proper scheduling of the CIP cycles, to prevent scale and the blockage of tubes with product deposits, and optimization of the amounts and types of cleaning agents for removing scale can also improve the heat transfer efficiency and hence reduce the total energy requirement. For example, cleaning using enzymatic agents can improve the cleaning efficiency, reduce the amount of chemicals needed, minimize the energy costs by working at a lower temperature and thus result in minimizing environmental impacts (Argüello et al., 2005).

In the manufacture of dried milks, after concentration to an intermediate total milk solids content, the milk is fed to drying systems. If the fluid milk itself was dried, significantly greater amounts of heat energy would be consumed. For example, the energy consumed in spray drying is 10–20 times higher, compared with evaporation, per kilogram of water removed (Ramírez, 1973). Therefore, the milk is first pre-concentrated as much as possible (to about 40–60% solids) by evaporation before being used in drying operations; this potentially contributes to energy savings, thus generating economic benefits as well as ecological benefits. The different methods used for the drying of milk and milk products include spray drying, drum or roller drying, oven drying, fluidized bed drying and freeze drying.

Roller drying, although used only on a small scale, still has considerable importance in applications such as milk powder intended for use in chocolates, infant milk formula and so on. The pre-concentrated and preheated milk is fed

on to a hot rotating roller to form a film. As the roller rotates, the film dries because of moisture loss and the dried film is scraped off with the help of scraper blades. The film of dried product is cooled and conveyed to a grinder, which mills the film into a fine powder. The surface of the roller or drum is kept hot by the heating medium, typically steam. The efficiency of roller or drum drying is quite low because a large amount of heat is lost from the roller surface. As the product is in direct contact with the heating medium, that is, the hot roller surface, for a comparatively longer time than for other drying methods, the sensory and nutritional qualities of the final product are adversely affected; therefore, this method of drying is not preferred in dairy industries unless it is specifically required for generating particular product characteristics.

The most commonly used drying method in dairy factories is spray drying with or without fluidized bed drying. In general, the different process control parameters for spray drying are the inlet and outlet temperatures of the heating medium (air), the type of atomizer in the drier, the feed temperature, the total solids content of the feed and the residence time. The pre-concentrated and preheated feed is sprayed inside a drying chamber. Hot air with an inlet temperature of up to 200 °C is introduced into the drier and the product droplets are dried rapidly. Generally, an outlet temperature of the exhaust air leaving the drying chamber of about 80–100 °C is maintained to achieve a high efficiency of operation and a high powder throughput.

Several energy conservation practices have been adopted during the drying process. Dairy factories have optimized the drying process and used as much heat as possible from the hot drying air by keeping the outlet temperature to the minimum possible. Furthermore, typically spray driers of about three or four floors in height are housed in an enclosed building. This not only is important from the viewpoint of food safety and hygiene but also helps in saving heat losses by radiation from the drier surface. Heat recovery systems, such as economizers, are being installed in the chimneys of steam boilers to recover heat from the exhaust gases.

A possible further improvement in the efficiency of spray drying operations is the recovery of both heat and powder fines from the exhaust gases (exiting from the drier). The loss of powder in the exhaust gases may range from 0.2 to 1.5% depending on the type of product (Kessler, 2002). This is undesirable not only for economic reasons but also because of its significant contribution to air pollution. Traditionally, a number of methods, such as bag filters and wet scrubbers, have been used to recover the fine powder particles from the exhaust air. A wet scrubber removes most of the powder particles. In this system, the exhaust air is passed through a spray of water, which retains the powder and thus reduces the amount of residual fines exiting to the atmosphere. These recovered powder fines dispersed in water can be used for the standardization of milk or for cattle feed. Wherever the use of wet scrubbers is not practical, the heat from the exiting air should be recovered as much as

possible by placing shell and tube type heat exchangers to minimize energy wastage (Kessler, 2002).

In summary, dairy industries have considerably improved the energy efficiency in the manufacture of concentrated and dried milks, which involves highly energy-intensive operations. Nevertheless, further energy savings using combinations of technologies, such as membrane filtration suitably combined with vacuum evaporation, can help to minimize environmental impacts.

7.3.3 Fermented dairy products

Fermented milk products, or cultured dairy products, is a collective name for a wide range of dairy products (yoghurt, cheese, cultured buttermilk etc.) in which fermentation takes place either by adding starter cultures (selected bacterial cultures) or by adding enzymes (such as rennet). In this section, we analyse the sustainability-driven aspects of the processing of cheese and yoghurt.

Cheese Cheese is a dairy product that is obtained by the acidification and the enzyme treatment of milk. Cheeses are often classified according to their structure (texture and body), flavour and appearance, and are grouped into the categories hard, semi-hard, semi-soft, soft and fresh cheeses (Bylund, 1995). The yield of cheese from milk is about 15–20% depending on the variety. The most common unit operations in cheese manufacture are heat treatment and standardization to the desired milk solids, acidification by acidifying agents or starter culture, addition of an enzyme such as rennet to form a three-dimensional casein gel, cutting of the gel, cooking of the curd, pressing, salting or brining for flavour and to extend the shelf life, ripening for flavour development, cutting, packaging and storage.

Most cheeses, for example, Cheddar, Gouda and Parmesan, are ripened. In addition to the energy considerations discussed for the processing of fluid milk, the other major energy-intensive areas in the manufacture of cheese are ripening and storage. Ripening is one of the most important steps in cheese manufacture for obtaining the desired flavour and texture. It is a process of storing the cheese under temperature and humidity conditions that are favourable for the growth of microbial cultures. The ripening time is generally between 3 and 12 months (or more for vintage cheeses) at 10–20 °C. The primary function of the ripening process is to develop flavour and texture by breaking down various components of the cheese, for example, fat, protein and lactic acid, using the enzymatic actions of various strains of lactic acid bacteria. During this process, the microflora cause chemical changes that lead to the development of flavour and texture. One or more sets of ripening conditions may be used during the manufacture of cheese. Moreover, the length of the ripening period can vary from a few weeks to months. Hence,

ripening involves significant energy consumption to maintain the desired temperature and humidity for such long periods.

Dairy industries have endeavoured to reduce the length of the ripening period by using various strategies, such as external enzymes, liposome-entrapped enzymes, genetically modified lactic acid bacteria, adding adjunct lactic acid bacteria cultures or leveraging the enzymatic activities of non-traditional microbial adjuncts, for example, yeasts (Soda and Pandian, 1991). Das (2004) has reported successful enhancement of the enzymatic activities of dairy yeasts by manipulating their growth conditions. The use of high levels of enzymatic activity to accelerate cheese ripening may lead to significant reductions in the ripening time and thereby energy savings. As the complex pathways for the formation of flavour compounds during ripening to be better understood, there will be greater opportunity to manipulate these pathways to create desirable flavours while reducing the ripening time.

The ripening time can also be minimized by carefully optimizing the size distribution of the fat droplets during homogenization of the milk. Michalski et al. (2006) have shown that Emmental cheese produced from milk with small fat globules obtained by microfiltration has a higher degree of proteolysis during ripening. Thus, by carefully altering the size distribution of the fat globules in milk during homogenization or using microfiltration techniques, the cheese ripening time can be shortened, providing potential energy savings.

Interestingly, the energy equivalent to manpower that is required for transferring the cheese blocks makes the ripening step even more energy intensive. Mechanical equipment, such as forklifts or trailers, also adds to the total emissions. Generally, dairy factories that manufacture cheese minimize their energy requirements by selecting suitable layouts and manufacturing designs. When ripening is to be carried out in stages, the ripening rooms are connected to each other so that the energy loss during transit is minimized. Large cheese factories use mechanical conveyors for transferring the blocks from one ripening room to the next. Some of the strategies that can further optimize energy requirements are full capacity utilization, use of battery-powered forklifts and planning multi-stage ripening, starting with the highest temperature and then ripening at lower temperatures, wherever possible. Intuitively, the transport and distribution time can potentially be used for ripening, especially in the case of the export of cheese to other continents. As New Zealand exports the majority of its cheese products to other continents, the concept of 'in-transport ripening' can possibly be carefully optimized by the selection of suitable cultures and enzymes to contribute to substantial energy savings.

In addition to energy considerations, the manufacture of cheese generates enormous amounts of whey. The disposal of whey has traditionally been an important issue for cheese factories and has been an area of academic research for decades. The utilization of whey and related sustainability initiatives are described in Section 6.3.5.1.

Yoghurt Yoghurt is a semi-solid fermented dairy product. Basically, milk is standardized with other dairy ingredients (e.g. skimmed milk powder, whey and lactose) to achieve the desired fat and milk solids-not-fat contents in the final product. The various ingredients (sugar, stabilizers such as carrageenan, etc.) are then blended together. The resulting mix is pasteurized using a severe heat treatment process (about 85 °C/30 min). This high heat treatment is essential to achieve the appropriate technological functionality, that is, to produce a relatively sterile environment for the starter culture and to denature the whey proteins for an enhancement of the viscosity and an improvement in the texture. As described in Section 6.3.1, the pasteurization conditions can be optimized to a large extent by minimizing the energy losses during the operation. Furthermore, the minimum temperature – time combination should be carefully selected to achieve optimum denaturation of the whey proteins (Dannenberg and Kessler, 1988; Tolkach and Kulozik, 2007). This will help to save energy, to avoid any nutritional losses as a result of an excessive level of whey protein gelation and finally to reduce the environmental impact.

After homogenizing the mix and cooling to an optimum temperature, the yoghurt starter culture, that is, *Streptococcus thermophilus* and *Lactobacillus bulgaricus* in a ratio of 1:1, is added and the mix is allowed to undergo the fermentation process (at a temperature of about 43 °C). Fermentation is one of the most crucial stages of yoghurt processing and usually ranges in time from 6 to 12 h. The coagulated product is cooled, fruit and flavours are incorporated depending on the product and the yoghurt is then packaged. It is stored at refrigeration temperatures (5 °C) to retard physical, chemical and microbiological deterioration before dispatch, and chilled transportation is required to distribute the product (Clark and Plotka, 2004). Hence, apart from pasteurization, the two ecologically critical unit operations are fermentation and chilled transportation.

As mentioned previously, the fermentation process consumes significant energy because higher than ambient temperatures need to be maintained for a significant period of time. Chr. Hansen has developed a new dairy culture, XPL-1, which can reduce the fermentation time needed for yoghurt processing by 3 h without compromising the firmness of the gel and thus can successfully contribute to energy savings. Another initiative from academic research that is worth mentioning is the use of the distribution time for fermentation (Jaworska, 2007; Nor-Khaizura et al., 2012). Jaworska (2007) has developed a yoghurt manufacturing concept called 'made-in-transit', which means that the whole or a part of the fermentation process is carried out during transportation and distribution by suitably manipulating the fermentation temperature–time and the milk total solids. To date, yoghurt manufacturers generally use a combination of a higher temperature and a shorter fermentation time. However, using this concept, the fermentation stage will be carried out over a longer time, but at ambient temperature during the distribution

chain rather than under controlled fermentation conditions in the manufacturing plant. Thus, this will allow energy savings in the dairy factories by leveraging the transportation time and temperature for fermentation and by removing the cold supply chain (e.g. involving refrigeration) requirement, which otherwise impacts on the environment significantly.

Reducing artificial additives and using more natural ingredients in dairy products are also part of the sustainability effort. Using the absolute minimum of ingredients to produce finished products might not only reduce the cost of production but also reduce the footprints generated in the production and supply chains of those ingredients. In 2012, Chr. Hansen launched a series of new Yo-Flex® starter cultures that are claimed to remove the addition of artificial ingredients such as stabilizers, thickeners and flavours to yoghurt without compromising its creaminess and texture.

Probiotic bacteria are one of the most successful and highly recognized functional ingredients in the food and beverage industries and are used mainly in product categories such as yoghurt, yoghurt drink and juice. Understandably, a technology that enables probiotics to be used in shelf-stable foods will increase the size of the probiotics market by tapping into additional product categories, trade channels and consumers. At the same time, significant energy can be saved by eliminating refrigeration during the transportation and storage of probiotic-containing dairy products. Several research groups in the commercial and academic arenas have been working on technologies to improve the stability of probiotics at ambient temperature. Nag et al. (2012) have recently developed and patented a technology that enables probiotics to be delivered in shelf-stable foods. Such technologies can also be employed in the manufacture of yoghurt, which might contribute to enhancing the environmental sustainability of its operation by reducing the refrigeration costs and the emissions during transportation and storage.

7.3.4 Fat-rich dairy products

The different fat-rich dairy products that are manufactured in dairy industries include cream and butter as the main products and anhydrous milk fat and butter oil as dairy ingredients. In this section, we discuss the processing of cream and butter and their environmental impacts.

Cream Cream is produced by the separation of whole milk (Figure 7.4). Separator manufacturers have made promising advances in terms of providing environmentally sustainable systems to dairy industries. Companies such as Tetra Pak and GEA Westfalia have introduced new generations of cream separators that allow high skimming efficiency with less power consumption and potential energy savings. Thus, they contribute not only to economic sustainability but also to environmental sustainability. GEA Westfalia has

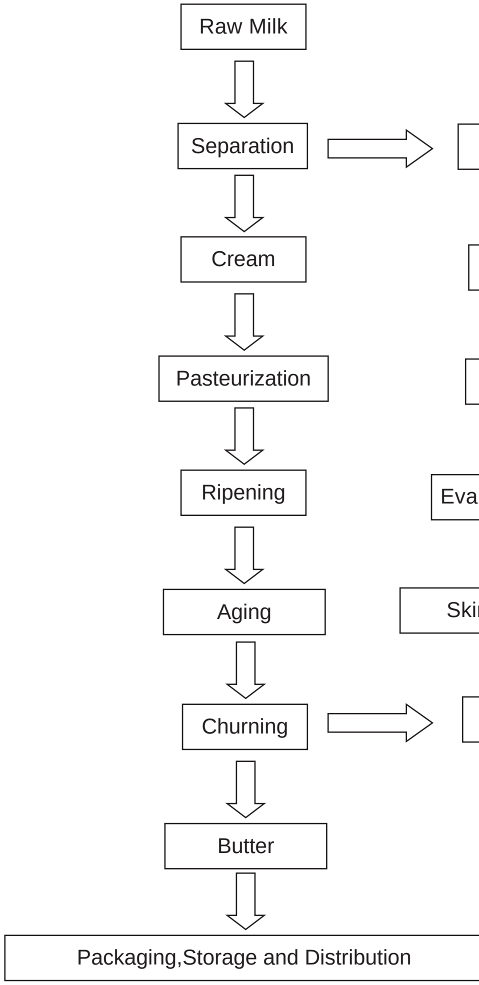

Figure 7.4 Flow chart of the operations in the manufacture of cream and butter.

introduced the 'ecocream' generation of separators, which combine the stages of milk clarification, separation and double bacterial removal (Melzig et al., 2012). These separators are claimed to provide 10% energy savings by using high efficiency motors. As these separators also help to remove the bacterial load, they can apparently help in minimizing the thermal energy requirements for microbial destruction.

One of the most important environmental issues from the manufacture of cream is the generation of huge amounts of by-product (skimmed milk). Historically, the skimmed milk, which is a rich source of non-fat milk solids,

has been used for standardization. It is pasteurized and usually concentrated and dried to create skimmed milk powder, which serves as an important dairy ingredient. The use of skimmed milk as an illustration of the dairy industry's promising sustainable efforts in reusing by-products is described in Section 6.3.5.2.

Butter The manufacture of butter is a multi-stage complex process, as shown in Figure 7.4. The cream obtained by separation is pasteurized at a temperature of about 95 °C. The severe heat treatment is needed to destroy enzymes and microorganisms that would otherwise impair the keeping quality of the butter. This huge energy usage during pasteurization clearly shows that butter making is an energy-intensive process. If ripening is desired for the production of cultured butter, mixed cultures (of *Streptococcus cremoris* and *Streptococcus lactis diacetylactis*) are used and the cream is ripened for flavour development at a lower pH for a significant duration. Intuitively, the best practices from cheese or yoghurt manufacture can be suitably adapted to manipulate the ripening temperature–time combination or the appropriate starter culture for a ripening process with minimal environmental impact can be used.

Cream (without or after being ripened) is aged using controlled cooling for a period of 12–15 h to provide the required crystalline structure of the fat. Thus, aging is an energy-intensive step. Modifying the fatty acid composition and the fat globule membrane of the milk through feeding cows with oil seed concentrates of different fatty acid compositions might be a potential route to improve the susceptibility of the fat to crystallize and thus reduce the crystallization time (Augustin et al., 2012).

From the aging tank, the cream is pumped to the churn or continuous butter maker via a plate heat exchanger, which brings it to the requisite temperature. In the churning process, the cream is violently agitated to disrupt the fat globule membrane, causing coagulation of the fat into butter grains and separation of the buttermilk (an important by-product). As well as pasteurization of the cream and cold storage requirements, which are in general the energy-intensive unit operations of almost all dairy processing, the generation of buttermilk poses a serious environmental threat if it is discarded to the wastewater stream. Using buttermilk as a product is common practice and is covered in Section 6.3.5.3. After draining the buttermilk, the butter is cooled and salted and then worked to a continuous fat phase, of more than 80% dairy fat, containing a finely dispersed water phase. To avoid the cooling step with additional chilled water, GEA Westfalia has introduced recirculation of the buttermilk in the butter making machine by a patented technology to ensure cooling of the butter granules, thus reducing the water and energy requirements (Lehmann et al., 1987). Furthermore, this recycling process might help in reclaiming and retaining some of the fat as well as the non-fat solids from the buttermilk in the butter, thereby improving the overall yield and reducing the loss of solids to the buttermilk.

Another significant reduction in the environmental impact of butter might be replacing part of the milk fat in butter by vegetable oil, thus reducing its milk fat content (Flysjö, 2011). Nilsson et al. (2010) have reported that 20–50% less energy is required for margarine products than for butter products, because the pre-farm gate contributes most to the environmental impact, particularly in terms of milk production for butter compared with vegetable oil production for margarine. Nevertheless, the replacement of dairy fat in butter would probably affect its quality and application and regulatory aspects of 'product identity' of butter containing vegetable oil in some countries. However, if the same technological functionality and sensory attributes could be retained while shifting to a lower fat content and to a higher proportion of vegetable oil in butter, the carbon footprints of the product would be significantly reduced.

7.3.5 Dairy by-products

For centuries, dairy industries have made remarkable efforts in using by-products. In particular, skimmed milk, a by-product from the separation of cream, whey, a by-product from cheese manufacture, and buttermilk, a by-product from butter manufacture, have attracted significant attention as they are seen more as valued commercial ingredients. The following subsections describe the efficient and effective conversion of such dairy processing by-products into ingredients, highlighting the promising contribution of dairy industries to environmental sustainability and economic benefits.

Whey Whey has been generated for 3000 years. Research efforts have transformed whey from a waste product to a valuable raw material (such as a source of whey protein isolates and concentrates, lactose, lactoferrin, bioactive peptides etc.), that is, from 'gutter-to-gold', by novel separation techniques (Smithers, 2008). The main focus of this section is to highlight some recent areas of whey utilization that have not only resulted in environmental sustainability (by reclaiming and using the by-product) but also generated significant commercial interest.

As introduced briefly in Section 6.3.3.1, whey is the watery liquid portion that is separated from the curd during the manufacture of cheese. Typically, whey contains about 6.5% milk solids and has a pH of 5.0–6.0 depending on the type of cheese (Zadow, 1986). It consists mainly of dissolved solids such as lactose and water-soluble whey proteins and a small amount of fat. The low solids content, high volumes and high biochemical oxygen demand of whey pose a major threat for disposal (Smithers et al., 1996). Traditionally, whey was drained, diverted to an effluent treatment plant for disposal or used for feeding cattle (Anderson et al., 1974). The last few decades have seen a gradual shift from whey being a waste stream to whey being a valuable source

of important ingredients such as lactose and whey proteins. Recent research has established the nutritional and functional role of lactose and whey proteins in foods. Whey protein has better nutritional quality than casein (Ha and Zemel, 2003; Hoffman and Falvo, 2004). It is rich in all the essential amino acids and has a protein efficiency ratio of 3.2, compared with 2.6 for casein, which is generally considered to be a reference protein. As its digestibility is very high, about 97–98%, it is close to being an ideal protein. It possesses bioactive peptides, which have potent roles in dealing with severe medical conditions such as cardiovascular disease, hypertension and obesity.

Strategies to utilize whey in dairy factories include standardization of the milk solids for fermented products such as yoghurt and cultured buttermilk. Whey and derived lactose are also used in: infant formula; bakery, dairy and confectionary products; animal feed and feedstocks; and several industrial fermentations (Yang and Silva, 1995). Continuous innovations in the field of whey proteins have led to the development of many highly valued products with improved functionalities and to alleviation of the huge waste disposal problem, and this is still an active area of research. Separation techniques such as electrodialysis, ultrafiltration, ion exchange and reverse osmosis have recently been used to produce a wide range of ingredients from whey (Schmidt et al., 1984). Some of the commercially available ingredients today include lactose, sweet and acid whey powders, reduced-lactose whey, demineralized whey, whey protein concentrates with protein contents of 34% (WPC34), 50% (WPC50), 60% (WPC60), 75% (WPC75) and 80% (WPC80), whey protein isolate containing not less than 90% protein and other valued ingredients such as lactoferrin, lactoperoxidase and glycomacropeptide, which are manufactured mainly by Fonterra, FrieslandCampina, Glanbia, Arla, Dairy Farmers of America, Davisco and Leprino (Luhovyy et al., 2007). Because it is a non-thermal technology, the separation of whey protein fractions without damaging their nutritional quality has a number of applications such as in sports nutrition, bakery products and some pharmaceuticals. On the one hand, whey protein is used as an emulsifier and texturizer in a range of products, e.g. ice cream, beverages and yoghurt; on the other hand, whey protein is used for its non-traditional value in nutritional supplements, clinical nutrition products and sports nutrition (Hoffman and Falvo, 2004). According to estimates by global dairy industry analysts, the demand for whey protein in nutritional products will grow to over 250 million kilograms per year in the USA by 2015. Thus, the utilization of whey for the production of these value-added products has not only generated economic value for dairy industries but also significantly reduced the environmental impacts associated with the disposal of whey.

Newer technologies are being developed to improve the functionalities of whey protein, such as improvement in gelling by treating with supercritical CO_2 (Zhong and Jin, 2008) and improvement in water-holding capacity by adding calcium (Clare et al., 2007). In collaboration with the Fonterra

Research Centre, New Zealand, Riddet Institute has been instrumental in the development of highly functional nanofibrils from β-lactoglobulin (a protein extracted from whey) (Loveday et al., 2010, 2012). Dairy protein nanofibrils have potential applications in the food industry because of their ability to enhance viscosity and to form gels at low protein concentrations. Hence, continuous innovations in the utilization of whey may lead to the development of many highly valued products with improved functionalities and to the removal of the huge waste disposal problem. As these new technologies become commercial, whey proteins will be more attractive to food industries, leading to further growth in whey processing and recovery and making dairy industries more environmentally sustainable.

It is worth mentioning that the utilization of whey by the dairy factory may be governed by a number of factors such as scale of operation, capital investment involved and technology availability. Whereas whey protein ingredients that are derived from whey by large scale dairy industries have a prominent share in the market, most of the whey produced by small scale industries is still not utilized. For example, India, the largest milk-producing country, discharges considerable amounts of whey as a waste stream. This is largely because the scattered nature of the production of whey (a by-product of traditional milk products such as *chhana* and *paneer*) makes the collection, processing and recovery logistically and economically challenging. It is crucial to target such small scale dairy industries and to collect the whey, which is a high quality protein source that can shield large sections of the global population from protein deficiency and can contribute to a reduction in environmental pollution.

Skimmed milk For centuries, milk fat was highly valued because dairy farmers obtained a premium price for supplying milk with high fat content. The introduction of the separator in 1878 allowed the efficient separation of cream (Henriksen et al., 2011). However, consequently, the skimmed milk that was obtained as a by-product after separation was used as an animal feed because it was not suitable for human consumption (Henriksen et al., 2011). Spray drying and the manufacture of skimmed milk powder was a significant development in dairy industries and led to the utilization of a by-product as a main ingredient (skimmed milk powder). The removal of water enables an extended shelf life and facilitates economical transportation because of the reduction in volume. Skimmed milk powder has also led to the development of recombined dairy products in many countries that do not have adequate fluid milk supplies (Sanderson, 1970; Kieseker, 1975; Barton, 1982).

Skimmed milk powder is widely used as an ingredient in many processed food products such as soups, sauces, recombined evaporated milk, confectionery and bakery products. Of the various components of skimmed milk, the casein micelles have the greatest impact in terms of its macroscopic and functional properties. A vast range of milk protein products, specifically

designed for particular end-use applications (emulsification, encapsulation), such as many different grades and types of caseins, caseinates and milk protein concentrates, can be manufactured from skimmed milk by manipulating the processing conditions during manufacture (Singh, 2002).

Over the last few decades, public health concerns, dietary guidelines, regulatory pressures in many countries, media interest in food issues and consequently overarching consumer demand for healthier foods have posed considerable challenges to dairy industries to design reduced-fat foods. Hence, skimmed milk has promise as a main product itself on market shelves and as the base for low fat cheeses, yoghurts and so on. This illustrates the pioneering efforts of dairy industries in reclaiming valuable solids from a waste steam and generating commercial gains, thus contributing significantly to environmental sustainability.

Buttermilk During the process of butter making (Section 6.3.4.2), cream undergoes churning, which involves aggregation of the fat globules and disruption of their fat globule (phospholipid/protein) membrane. This membrane material, together with most of the water-soluble materials, is released into the aqueous phase, called buttermilk (Corrideg et al., 2003). Although buttermilk is a by-product of butter manufacture, it is widely used in the manufacture of cultured milk products and in the standardization of milk for yoghurt, milk powder and so on. Buttermilk is also concentrated and dried to produce buttermilk powder, which is used as an ingredient in bakery and confectionary applications. This both generates economic benefits and solves the environmental issue of waste disposal.

Buttermilk has also recently been recognized as a potential source of phospholipids (Sachdeva and Buchheim, 1997; Singh, 2006). Researchers have demonstrated that the addition of sodium citrate to buttermilk (to dissociate the casein micelles) followed by membrane filtration allows the permeation of skimmed-milk-derived proteins and the generation of a retentate that is rich in milk fat globule membrane (MFGM) fractions (Corrideg et al., 2003). Thus, buttermilk is a by-product of increasing importance because it is a potential source of novel functional ingredients such as milk-based phospholipids.

Recently, to evaluate the benefits of such MFGM materials in applications, Le et al. (2011) prepared yoghurts with increased concentrations of MFGM-enriched material (isolated from buttermilk using microfiltration) and reported that the yoghurts had denser gel structure, increased water-holding capacity and stronger adhesiveness. Thus, intuitively, the desired gel strength might be achieved in yoghurt by the optimization of MFGM material and a reduction in other milk solids, contributing towards sustainability. This indicates that buttermilk can be used to develop new value-added functional ingredients using novel non-thermal membrane technologies, which might be of both technological and nutritional importance in main stream dairy

products, thus contributing to commercial benefits. At the same time, from a sustainability point of view, this illustrates the utilization of significant amounts of a by-product from dairy processing, which otherwise would have been discarded, causing environmental pollution.

In summary, the unit operations involved in the manufacture of different dairy products are associated with significant environmental impacts. However, dairy industries have made valuable efforts in promoting sustainability by reducing energy usage, increasing the efficiency of operation, reclaiming and utilizing by-products using novel technologies for the generation of functional dairy products and managing water resources. The overall aim of dairy processing should be to integrate the best practices in different unit operations that not only decrease carbon footprints or increase the efficiency of operation but also target zero waste. Furthermore, academic research as well as commercial scale-up operations in the field of non-thermal emerging technologies, such as ultrasound, high pressure, cool plasma and pulsed electric field processing, are required to realize long-term economic and ecological sustainability (Augustin et al., 2012).

7.4 Sustainability initiatives in dairy packaging

Packaging is integral to the processing of any food product. It helps to preserve the product's quality until its consumption. It is the first contact of the consumer with the food on the market shelves and thus plays a pivotal role in influencing the buying decisions of consumers. The generic functions of packaging in food products include preserving quality, preventing the access of chemical and microbial contaminants and containing the product during its distribution and so on. Some of the other functions of the packaging of food products of commercial importance are differentiation from a competitor product or brand (e.g. tetrahedral milk packs from Tetra Pak), better traceability, a means of communication with the consumer (nutritional information, directions for use) and convenience (different pack sizes). Readers are referred to Robertson (2006) and Yam (2009) for in-depth information on progress in the area of food packaging.

With the increasing demand for processed food products, a variety of new products is launched each year. Advances in science and technology over the past few decades have introduced materials such as plastics and multi-layered laminates containing metal layers that make the package structure more complex. This has resulted in an increased amount of waste packaging post-consumption, which raises concerns about their use because of their lack of biodegradability. Persistent public concern that packaging waste contributes significantly to landfill space and greenhouse gas emissions has radically driven consumer preferences towards packaged products of lower environmental impact. Thus, in addition to the basic requirements of an ideal packaging material, such as good barrier properties, strength and convenience,

its ability to be recycled has recently assumed importance. Chapter 12 deals with sustainability initiatives in food packaging operations. Nevertheless, we discuss packaging concerns and best practices from the standpoint of dairy sustainability.

The choice of a packaging material for a dairy product depends primarily on the requirements of the product. Dairy products containing fat are prone to rancidity and hence require good barrier properties against oxygen, water and light. The different packaging materials used in a dairy factory include glass bottles, treated paper and laminates of paper and/or metal, co-extruded low density polyethylene pouches or cans, metal tins and paper bags. Because of the short transit time from the factory to the point of consumption, there have been few changes in the packaging of market milk except for a reduction in density of the material to reduce the cost of packaging. Similarly, the packaging of ice cream, butter and fat-rich dairy products has remained relatively simple, with a few recent advances in the use of nitrogen flushing and the packaging for fat-rich products. However, one of the noteworthy developments in dairy packaging is the use of multi-layered laminates containing metal layers for the packaging of UHT-treated milk. These laminates have eliminated the need for a refrigerated supply chain to maintain the quality of these milks, thus saving energy and reducing emissions associated with the frequent transportation of milk to remote regions.

The most commonly used approach to assess the impacts of packaging materials on the environment is LCA. This comprehensive approach takes into account the environmental impact, from the raw materials to the recycling or disposal stage. As well as energy requirements, it also includes impacts on air, water and land. Using LCA, Hanssen (1998) showed that shelf-stable milk in aseptic packaging contributed about 55% of the total fossil fuel used for the total life cycle of the milk package (Hanssen, 1998). However, Hanssen (1998) stated that the contribution of production and processing was significantly greater than that of the packaging. In another recent study, an LCA for cheese packaging suggested that decomposition of the package in the landfill had the greatest environmental impact in producing greenhouse gas emissions (Banar and Çokaygil, 2009).

Different strategies have been used to make dairy packaging more sustainable. Greiner Packaging (Micheldorf, Austria) has plans to invest £2.7 million in the recycling of plastic containers and the reuse of packaging for products such as cream, yoghurt and desserts. This will prevent about 4000 bottles from being diverted to landfill space each year (Glaberson, 2011). With the availability of a wide range of plastics and their different properties, it is now possible to customize the packaging material according to the characteristics of the product. The packaging of milk has seen a revolution from glass to thin multi-layered co-extruded plastic. This has helped in reducing both the cost and the emissions associated with transportation.

The responsibility of dairy factories should also extend to post-consumption at the consumer level. Factories can sub-contract the collection of empty packaging, which can be recycled. To motivate consumers to return the empty packaging, the dairy cooperative sector in India (Amul) has made an excellent effort by offering trade discounts on future purchases for each return of a fixed number of empty packs. These types of scheme not only build a cleaner image for the organization but also educate and motivate consumers towards the advantages of recycling packaging. Although packaging may contribute only a small portion of the greenhouse gas emissions for the entire life cycle of a dairy product, initiatives in reducing packaging waste by recycling can contribute to the creation of a sustainable dairy value chain (Milani et al., 2011).

7.5 Sustainability initiatives in utilities and services

Sustainability in the utilities section of dairy industries is cumbersome because it includes resources such as water and energy. This section on utilities identifies interesting sustainable initiatives with reference to the dairy sector in terms of the reuse or minimization of the wastage of water and energy.

7.5.1 Water

Of all the utilities and services used in a dairy factory, water is one of the most important resources. Generally, dairy factories utilize water supplied from municipal councils or local civic authorities, pre-owned or contracted bore wells and so on. Water is used in different unit operations such as heating and cooling, cleaning, product manufacture and steam production. The water used in a dairy factory can be broadly categorized into two groups based on its contact with the product (New Zealand Food Safety Authority, 2006). Contact water is the water that comes into contact with the product or the equipment surface. This type of water is used in product formulation and standardization, in the preparation of brine solutions for the wet salting of cheese, as the final rinse water after CIP and so on. Non-contact water is the water that does not come into contact with the product and is used for applications such as general cleaning and CIP, and as a heat exchange medium for the heating and cooling of the products. Thus water forms an integral part of the utilities required by any dairy factory.

The average consumption of water varies with the location of the factory and the type and number of products being manufactured at the dairy factory (Carawan et al., 1979). The literature suggests a wide range of data for water usage in dairy factories. It is estimated that water consumption in dairy factories ranges from 0.2 to 11 L/L milk in Europe (Daufin et al., 2001), is

up to 3 L/L milk in Australia (EEKT, 2004) and is about 2 L/L milk in tropical countries such as India (National Bank for Agriculture and Rural Development, 2007). Of the different unit operations, cleaning and CIP consume about half the total water used in the dairy factory. This is followed by water for heat exchangers, which contributes to just over a quarter of the total water consumed (Prasad et al., 2004).

The past few decades have seen an unprecedented demand for water of clean potable quality. The increasing population, rapid industrialization and its effects such as global warming have led to disturbances in the water cycle balance. Rapid urbanization has resulted in the pollution of traditional water reservoirs such as rivers and ponds and has caused a lowering of groundwater levels. The International Water Management Institute in Sri Lanka, as input for World Water Vision, estimated that as many as 3 billion people, that is, nearly one-third of the world's population, will face a major water crisis by 2025 (International Water Management Institute, 1998). In regions where water is scarce, the water supplied to dairy factories may need to be transported several hundred kilometres by rail or road. This not only increases the cost per litre of water but also leaves carbon footprints because of emissions during transportation. Thus, a dairy factory is presented with a challenge to conserve water and to aim towards becoming 'water positive' or, optimistically, a 'zero water factory' (Augustin et al., 2012).

Realizing the importance of conserving water in different operations, dairy factories have already taken measures to reduce, recycle and reuse water by improving efficiencies and investing in superior technologies. Using a dairy-based biological reactor, Fonterra's Stirling processing site in New Zealand converts 3.5 million litres of process water into treated water that resembles tap water, contributing towards water sustainability. Similarly, Arla's proposed Aylesbury unit in the UK aims to process milk using only 0.2 L water/L milk and plans to reduce the overall use of water by about 20% by 2015.

Water usage can also be minimized by careful planning of processing operations. Some initiatives include optimizing CIP cycles, utilizing treated effluent for farm activities and investing in water recycling systems. For example, the rinse water containing milk solids before the commencement of CIP cycles can be collected separately and used for the standardization of fluid milk. With the help of advanced methods, dairy factories have switched from a traditional seven-step CIP cycle to a mere three-step cycle (Watkinson, 2004). Different innovations in CIP, such as using ozone (Qadir et al., 2007), design of the spray balls (Packman et al., 2008), cleaning solutions and the use of sophisticated software to simulate cleaning conditions, have led to improvements in the cleaning efficiency and reductions in water usage. Eide et al. (2003) performed LCAs on four CIP methods (conventional alkaline/acid cleaning with hot water disinfection, one-phase alkaline cleaning with acid chemical disinfection, enzyme-based cleaning with acid chemical disinfection

and the conventional method with disinfection by cold nitric acid at pH 2) and reported that CIP methods using small volumes and low temperatures, such as enzyme-based cleaning and one-phase alkaline cleaning, were the best alternatives for reducing environmental impacts.

Zoning of the manufacturing facility into regions that require different levels of cleaning is widely used in food factories to maintain hygiene levels. Some regions will require controlled cleaning to improve hygiene and reduce microbial loads around the product handling area. Food multinationals such as Cadbury, Nestlé and Unilever have successfully adopted dry cleaning methods for improving the hygiene of their manufacturing operations. Such dry cleaning methods can be employed in dairy factories in dry product regions, such as powder production and packing sections, by using compressed air, thus significantly reducing water usage.

The collection of steam condensates from different equipment also presents a useful opportunity to conserve not only water but also the heat contained in the condensate. Typically, jacketed equipment such as kettles, batch pasteurizers and condensing plants use large amounts of steam. The condensates from their steam traps can be collected centrally and reused as feed water in boilers.

Although dairy factories already have initiatives to reduce, reuse and recycle water, sourcing water from sustainable sources would also contribute to an improvement in water management. Rainwater harvesting is one such sustainable approach. This requires the collection of rainwater, which otherwise would run off through the catchment area, for its future use (Boers and Ben-Ashar, 1982; Qadir et al., 2007). Mother Dairy in India is harvesting about 59% of the rainwater on its total rooftop surface area and is using it in its dairy operations. Coca-Cola (Atlanta, GA, USA) has rainwater-harvesting facilities at 22% of its locations. It has been promoting rainwater harvesting by setting up harvesting facilities at 320 locations across 17 states with the help of non-governmental organizations, local governments and communities. Similar practices by dairy organizations will also help to reiterate their commitment towards the environment and local communities.

Membrane processing and reverse osmosis have been used for treating dairy effluent (Koyuncu et al., 2000; Balannec et al., 2002; Sarkar et al., 2006). Although it is capital intensive, membrane processing has several advantages. Because it is a non-thermal process and requires comparatively short residence times compared with conventional treatment processes, a final treated water of superior quality can be obtained. In line with sustainable water resourcing, water treatment initiatives using advanced technologies would definitely increase the extent of water reuse and recycling.

7.5.2 Energy

Energy is another major utility in dairy factories and forms the major input in terms of the cost of processing, because milk has to be kept at low

temperatures during transportation and storage and at high temperatures during processing operations (Figure 7.1). Thus, energy, in the form of thermal treatment or refrigeration, is a significant contributor to greenhouse gas emissions in dairy processing irrespective of the type of dairy product manufactured.

Increasing urbanization has resulted in increased demand for fossil-fuel-generated electricity for both domestic and industrial use. This has caused an imbalance in the supply–demand ratio and hence an increase in electricity prices. With the introduction of the carbon emissions trading scheme in various part of the world, such as Australia, the cost of energy is set to rise further because of the carbon footprint associated with electricity production. Thus, it is vital for dairy factories to become energy efficient if they are to be both environmentally and economically sustainable.

Typically, the energy utilized by dairy factories can be grouped into two broad categories: electrical energy and thermal energy. Electricity is used for purposes such as driving process equipment, lighting, heating, running refrigeration systems and operating the boiler for steam generation. Electric power can be purchased from electricity companies or may be generated in-house. Thermal energy is typically used for heating water or generating steam. It is generally produced in-house on dairy premises by the combustion of fuels such as natural gas, oil or coal. Most dairy processes use a combination of these energies during operation; for example, a pasteurizer system may use electricity for pumping milk, whereas milk may be heated by hot water heated through steam. Similarly, a CIP system may use the steam generated by thermal energy to heat CIP solutions, whereas the pumping and control operations may use electrical energy. Thus, any savings in either type of energy may help to keep the cost of production low and to reduce environmental impacts.

Electricity purchased from power companies may be produced by different means, *e.g.* the hydro energy of flowing rivers or water, thermal energy by the combustion of fuels, wind energy, tidal energy and, to a lesser extent, nuclear energy. The impact of electricity generation from these sources on the environment can be measured in terms of equivalent CO_2 released during production. The advantages and drawbacks of these sources of energy are beyond the scope of this chapter. However, from the viewpoint of sustainability, the combustion of fuels is least preferred because of its large carbon footprint on the environment. Although other sources such as wind energy, tidal energy, nuclear energy and solar energy are considered to be relatively clean energy sources, their utilization is dependent on a number of factors such as location of the plant, technical knowledge available for disposal, environmental conditions, capital investment and government policies.

One important way to reduce energy usage in dairy industries is to use cold pasteurization, the lactoperoxidase–hydrogen peroxide–thiocyanate (LP) system that is inherent in milk, rather than thermal treatment (Reiter and Härnulv, 1984). Lactoperoxidase, an enzyme that occurs naturally in milk,

acts in the defence against microbial activity in raw milk in the presence of thiocyanate and hydrogen peroxide. Because of its bacteriostatic effect, the LP system can maintain the initial milk quality for 4–7 h at 30–35 °C and 24–26 h at 15 °C (Bjorck et al., 1979). Although this might not be an alternative for the thermal pasteurization of milk in processing plants, it can definitely help to preserve the raw milk for a short time, for example, to preserve the quality and hygiene of milk in collection centres in developing countries, and thus can potentially contribute to energy savings.

Another major area in a dairy factory that consumes significant amounts of electrical energy is the refrigeration systems that are used for cooling operations in equipment and storage tanks and for maintaining low temperatures in cold stores and freezers for ice cream. Chilled process water is required for cooling products after heating and for condensing the refrigerant in conventional refrigeration systems. Conventionally, ice banks are used for chilling water to 1 °C for these purposes. They not only are energy intensive but also require a long time for the regeneration of ice. Advances in refrigeration science have led to new technologies for chilling and cooling purposes. Mother Dairy, India, which manufactures a host of milk products that are marketed under the brand name Amul, has successfully installed a more efficient vapour absorption system for the chilling of process water.

Similarly, freezing and the frozen storage of products is one of the most energy-intensive operations in food industries. The inherent characteristics of a product such as ice cream require it to be kept at temperatures below −18 °C from the time it is produced until it reaches the consumer. Generally, dairy factories use ammonia as the refrigerant for all purposes, whereas retail outlets use commercial refrigerators using hydrofluorocarbon (HFC) compounds for keeping their products at low temperature. In the cold chain in dairy factories, heat gain from the atmosphere is minimized by suitably insulating refrigerant lines and cold stores, selecting sliding doors for walk-in freezers, designing a buffer room outside the entrance to minimize heat gain during loading and unloading operations and so on.

The energy consumed by refrigeration systems can be further reduced in a number of ways, for example, designing the cold stores and walk-in freezers below the building to prevent exposure to the atmosphere. Such a design would also be more energy efficient in that product could be conveyed to the storage area by gravity. Moreover, cold stores can be housed in the same area to minimize surface area and to reduce heat gain. Similarly, switching to greener environmentally friendly refrigerants for ice cream production and storage will minimize damage to the environment. Since 2007, advanced hydrocarbon-based refrigeration systems instead of conventional HFC refrigeration systems have been used in ice cream freezers in India for Unilever's ice cream brand Kwality Walls. These systems are more energy efficient than the HFC-based systems, reducing the carbon footprint and causing less damage to the environment.

In addition, careful production planning by reducing processing operations during times of peak electricity demand and shifting to low peak demand periods, wherever possible, can make dairy operations more sustainable. By ensuring full capacity utilization, dairy industries can maintain the ratio of real power to apparent power closer to unity to minimize power wastage. Replacing old motors and a regular maintenance schedule for equipment can increase efficiency and reduce energy consumption. Each item of equipment should have its own equipment control and maintenance record, which should record all the details such as a log of maintenance done or its due date, procedures for safe operation, grades of lubricant if any and names of trained operators. The electricity consumed by buildings and equipment housings can be reduced by using low power consumption and fluorescent lights activated by motion sensors. Furthermore, wherever possible, solar energy can serve as a viable greener alternative to electricity.

Solar energy is slowly becoming popular; most parts of the world get adequate sunlight, which can be used easily, whereas other sources such as wind energy or nuclear energy require sophisticated instrument set-up or technology. Solar panels can be installed on the roofs of buildings and can be used for a number of purposes such as lighting and heating or even for the power supply of computer-controlled equipment. In processing areas, solar energy can be used to heat water for processing or steam generation and also for generating the power supply for automation systems. In many countries, governments are providing incentives for organizations that use solar energy, including subsidized equipment and installation, technical know-how and tax cuts. Thus, solar energy in dairy factories is a clean, sustainable and financially viable alternative to conventional sources of energy. Other approaches used by factories include co-generation; for example, at its Gloucester, UK, ice cream factory, Unilever has been able to cut CO_2 emissions by about 3000 tonnes per year by producing electricity and heat using natural gas and thermal energy. Similarly, Fonterra has been able to reduce its energy needs by up to 25% by using co-generation.

Carbon emissions associated with the combustion of fuel during steam generation are one of the major sources of the overall carbon footprint from dairy factories. The different types of fuel used in steam boilers include petroleum products such as diesel and oil, coal, wood and natural gas. Industries also often use agricultural wastes such as rice husks and bagasse as fuels for steam production. Using biodigestors, dairy factories can convert organic wastes generated from processing operations to biogas, which can be used to replace fossil fuels in boilers. Fonterra's Tirau facility in New Zealand uses waste generated from whey processing to produce biogas, which is used for steam production. Similarly, Unilever's Hellendoorn (The Netherlands) Ben & Jerry's ice cream factory aims to reduce CO_2 emissions by about 500 tonnes by using a biodigester to convert waste into biogas.

Thus, there is still huge scope for conserving energy in dairy factories and reducing the carbon footprint from different operations by making processes more efficient, adopting superior technologies and utilizing waste for the production of biofuels. As dairying is one of the most energy-intensive industries, any savings in energy will have a tangible and immediate effect, which will be reflected in positive financial statements. Further, as part of corporate social responsibility, dairy factories can extend such energy-saving initiatives to their suppliers. For example, as part of its sustainability vision, Fonterra has launched a drive to improve the energy efficiency at about 150 farms by conducting energy audits and helping farmers reduce expenditure on energy by up to 10%, saving around $NZ16 million annually.

In summary, water management and energy management are not generic across the diversified areas of dairy processing. The approaches for the efficient utilization of water and energy resources and for reducing environmental impacts from utilities are largely dependent on the processing requirements of a particular dairy product. Processing steps need to be carefully studied and the potential for the reuse, recycle and replenish of water, energy and other utilities (such as chemicals for cleaning) needs to be meticulously identified.

7.6 Sustainability initiatives in transportation

Whereas it is always desirable to have factories located close to the production farms, this is not practically possible for a number of reasons. The location of a dairy factory is often dependent on the products it manufactures. Factories that manufacture a mix of products tend to be located towards urban areas away from farms and hence require the milk to be transported from the farms. Dairy factories use milk tankers with capacities from 10 000 L to more than 30 000 L for the transportation of milk. Wherever possible, milk is also transported long distances in insulated train wagons. Refrigerated road or rail containers are also frequently used for the transportation of frozen products. The transportation of milk can result in significant emissions from vehicles. In addition, any refrigeration during transit, *e.g.* refrigerated vans, further increases the total energy consumption and adds to the emissions. Thus, any step in rationalizing the transportation of products can cut emissions significantly.

Rationalization of the collection routes and the frequencies of collection has been well studied. Wherever milk production is scattered, that is, the farms are distant from the processing plants, dairy factories have set up intermediate milk collection centres at which milk from different producers is pooled, collected and chilled to less than 4 °C. The chilled milk is then transported to factories for further processing. This not only reduces the chances of spoilage but also indirectly ensures sustainable handling. In summary, dairy industries have already taken a lead to optimize the collection or transportation of milk and to minimize the emissions per kilogram of milk transported. Innovations

in the automobile industry have further eased the load of emissions from milk transport vehicles. Over the last four years, Fonterra in Australia has been able to reduce its diesel consumption by using B-double trucks, which consume less fuel per kilogram of milk transportation.

The concentration of milk prior to transportation has huge potential to reduce milk transportation emissions and costs. Fluid milk with milk solids of about 14–16% can be pre-concentrated to an intermediate total solids on farms using technologies such as reverse osmosis, reducing the bulk to be transported and significantly contributing to environmental sustainability. Such milk is reconstituted back to the desired solids on arrival at the dairy factory. Thus, for a refrigerated tanker of fixed capacity, such an approach removes the bulk water so that an equivalent weight can be replaced by milk solids. Fonterra's Clandeboye site in South Canterbury, New Zealand, has successfully adopted this approach to concentrate milk solids on the farm prior to collection. This has saved about 3000 tanker trips per year, cutting the emissions from these trips by 1350 tonnes. Following this success, Fonterra also plans to contribute to its commitment towards environmental sustainability by implementing this approach of the pre-concentration of milk on farms in the Culverden region of New Zealand.

Other significant measures to make dairy transport more sustainable include the use of rail wagons instead of diesel-operated tankers wherever possible, upgrading the old fleet with tankers that are more fuel efficient, using biodiesel in all factory vehicles and setting up a milk grid between different dairy factories in the region. For example, by using rail wagons to transport dairy products, Fonterra New Zealand has eliminated 45 000 truck movements on the highways, saving CO_2 emissions of about 9000 tonnes. Moreover, during the peak of the season, Fonterra has been able to reduce the fleet size by 5% by the inter-site transfer of milk.

Indirect measures, for example, government policies, make the transport operations even more sustainable. The temporary approval by the New Zealand Transport Agency for an increase in the operating weight of tankers by 5 tonnes apparently increases the capacity for milk collection by 1.2 million litres per day, reducing extra trips and cutting CO_2 emissions. Thus, dairy factories across the world have made comprehensive efforts to make transport more sustainable.

7.7 Future strategies for environmental sustainability

The future direction of sustainability in dairy industries will focus mainly on three key approaches:

a) waste reduction, resource efficiency (e.g. water and cleaning agents) and value addition;

b) reduction in energy usage as well as the use of alternative energy;
c) implementation of emerging technologies.

Extensive research in science and technology will be needed to reduce carbon footprints and develop strategies for the sustainable management of water, energy and other natural resources in order to design greener, that is, low environmental impact, dairy products. Recent trends in dairy processing with respect to the demands of functional ingredients might change the product mix of future dairy industries. Improvements in membrane technologies and novel separation techniques might be the potential route to allow valuable functional ingredients to be reclaimed from by-products such as whey and buttermilk and to build a 'zero waste' plant. Fouling in heat exchangers due to whey protein denaturation, and biofilm formation continues to be a significant issue in dairy factories. Future strategies for improving cleaning efficiencies and sanitation could include the introduction of the new generation biocidal and enzymatic cleaning agents, a reduction in chemicals and the alteration of surfaces to reduce the formation of biofilms (Lowry, 2010).

Research efforts will continue to develop process equipment with higher energy efficiency. For example, a collaborative programme between Dairy Australia and NIZO (The Netherlands) is working on developing self-cleaning heat exchangers to reduce fouling and eventually to reduce energy consumption. The same programme is also aiming to develop a high solids spray drying technique to reduce the energy requirement in spray drying. Future sustainability practices will also enable the proper design of dairy factories to maximize the utilization of natural energy, for example, sunlight, (for lighting) and gravity (for liquid transportation). It is well known that on-site wastewater treatment is extensive in many dairy industries to reduce the biochemical oxygen demand of the discharged water (Milani et al., 2011). The possibility of generating renewable energy from dairy effluent streams is being explored. Trials have indicated that 1.3 GWh of energy could be produced annually from the effluent of a typical large dairy processing factory using a microbial fuel cell. Arla, in collaboration with its academic and industrial partners, has successfully scaled up this technology, which may be able to make dairy operations completely energy neutral in the future, that is, all the required energy in a dairy factory might be produced from its own waste streams.

Finally, sustainability in dairy industries will be achieved only by a systematic approach for waste and energy reduction and efficient utilization of resources at various stages of dairy processing, thereby resulting in the cost-effective conversion of milk into value-added dairy products. In the future, dairy industries are expected to use many of the currently used unit operations such as heating, homogenization, concentration and drying. However, in addition to executing these processes more efficiently, dairy industries

might be implementing some of the emerging technologies that involve milder processing, such as high pressure technology, ultrasound and pulsed electric field, which are currently being explored at research levels (Augustin et al., 2012). It is well recognized that the traditional thermal processing used for pasteurization or concentration and drying involves a temperature–time process design that requires significant amounts of fossil fuels and water (Pereira and Vicente, 2010). It might be argued that novel technologies, which are generally powered only by electricity, might be more sustainable than traditional thermal processing approaches, by reducing the use of steam generation systems, minimizing wastewater and thus increasing water and energy savings. Collaborations between academic research institutes and dairy industries are imperative to understand the real sustainability benefits of these emerging technologies. Integrated approaches need to be adopted to merge beneficial non-thermal technologies with traditional processing to ensure the production of safe, healthy and nutritious dairy products, with environmental footprints being reduced to the absolute minimum.

7.8 Conclusions

Along with all other sectors of human civilization, dairy industries have undertaken their commitment to sustainability, that is, reducing their environmental footprint, while supplying nature's most nutritious food to the ever-increasing world population. Dairy industries leave their environmental footprint at different steps in the value chain, for example, fodder production, rearing of dairy animals, milk production, processing, packaging, distribution, storage and retail, until the product reaches the consumer. We can empirically divide the value chain into pre-farm gate and post-farm gate. To fit with the central theme of the book, this chapter has focused mainly on post-farm gate and has investigated traditional as well as advanced processes and practices that are used to reduce environmental footprints. Interestingly, these processes not only reduce environmental footprints but also improve the nutritional integrity of the products by reducing nutrient damage (e.g. by reducing heat treatment), improving profitability (e.g. by reducing processing loss and reducing energy usage) and providing consumers and food companies with new functional ingredients (e.g. whey-derived ingredients), creating a real win – win situation for every stakeholder of the industry.

In 2009, the dairy sector signed its Global Dairy Agenda for Action on Climate Change, which obliged dairy industries to reduce greenhouse gas emissions. This agenda was signed by seven major global dairy organizations that represent dairy industries from various geographies and various parts of the value chain. The two-year report showed satisfactory progress in reducing environmental impacts (GDAA, 2011). With this high level of commitment from dairy industries, the continuous development of

advanced processing technologies and the profitable situation for each stakeholder put dairy industries at an advantageous position in the sustainability journey. Nevertheless, scientific research efforts for leveraging novel technologies and prominent corporate social initiatives for minimizing ecological footprints are essential to further develop strategies for 'green dairy processing'.

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8 Meat Processing

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8.1 Introduction

Over the years the meat processing industry has seen much development both in product innovation and mechanization. It is one of the thriving sectors of the food and drink industry that has seen great expansion as the world's population and the demand for high rich protein diets increases. In addition to the farming of animals to feed the meat industry, the meat industry consist of three integrated sectors which include the primary processing or fresh production (including harvesting and fresh meat processing); manufacturing or secondary processing (including the manufacture of further processed meat products); and processing support (equipment, ingredients, chemicals, packaging materials, transport and other services). Specifically, the meat industry covers: the slaughtering of animals including cattle, sheep, pig, poultry (chicken, turkey, and ducks); production and preserving of meat and poultry meat; bacon and ham production; other meat and poultry meat processing and animal by-product processing. This chapter will focus on these topics by considering the slaughtering process (as primary processing) and the processing of meat and poultry meat products (as secondary processing).

Sustainability in the meat industry is not a new word. The topic of sustainability has been with the meat industry since the publication of Upton Sinclair's *The Jungle* in 1906 (The Project Gutenberg Ebook, 2010) and continues to receive much attention in recent years. The book identified the labour and environmental conditions of the meat industry (also referred to as the meatpacking industry). The large amount of acreage required for grazing, corn for finishing, and water for processing beef, pork and other

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animals cannot be over emphasized. However, there is evidence that all players in the meat and for that matter food and drink industry are making every effort to develop policies, procedures and making technology available for the sustainable production of meat and meat products. However, in a report on the economic and environmental impact of meat consumption, Fiala (2006) concluded that current meat production systems is not sustainable, and so a range of issues must be dealt with by governments of the world sooner rather than later. In the literature, the main issue has been with the farming of animal to produce the raw material for meat processing. The meat processing industry has not been put to the spotlight yet, even though it also generates some amount of waste and emissions that could impact the environment by contributing to greenhouse gases and general environmental pollution. Meat production and processing was ranked in the top five contributors to all environmental impacts in the European Impact of Products (EIPRO) analysis of the life cycle environmental impacts related to the final consumption of the EU-25 (Tukker et al., 2006).

This chapter will cover the economics of the meat industry, the sustainability issues of meat processing (from slaughter to manufacturing), what actions are being taken by the industry on sustainability matters and the way forward for the meat industry.

8.2 Economics of the meat industry

The meat industry has a lot to contribute to the economy of any one community or country as implied in various reports (Zhou et. al., 2012; Scollan et al., 2010; Agricultural Marketing Services Division, 2002). The production and consumption of meat and meat products has continued to increase over the years as the population of the world increases. As indicated by Thankappan and Flynn (2006); the global meat consumption of meat and meat products has tripled since the 1960s and continue to increase rapidly. However, despite the continued campaigns to reduce the consumption of meat this has not stopped this increase. To meet this increase, the industry had to respond by correspondingly increasing the production of meat and meat products. It is estimated that, following current consumption patterns, the amount of worldwide meat consumption in 2030 will be 72% higher than that consumed in 2000 (Fiala, 2008). FAO (2003) estimated that the trend towards the increased meat and meat products consumption will continue in developed countries reaching 100 kg per person per year in 2030 from the current world average consumption of 47 kg per person per year. Depending on culture and preferences this differs from region to region, and in 2004 meat consumption in Spain was reported to reach 135 kg per person, exceeding the 2030 projection by the FAO. Meat consumption *per capita* is shown in Table 8.1 for selected developed countries and immerging economies. Whereas meat consumption *per capita* continue to increase in emerging economies such as Brazil, it

Table 8.1 *Per capita* meat consumption (Kg per person) in selected countries

	2008	2009	2010	2011
USA	121.67	118.90	117.50	114.80
Australia	91.95	92.70	98.00	98.50
Canada	91.68	90.03	87.27	86.70
Brazil*	90.13	91.22	97.59	100.19
EU-27	78.27	78.14	78.00	77.20
Russia	60.36	59.11	60.25	61.89
New Zealand	49.84	48.65	49.66	46.10
China*	49.19	50.47	52.03	51.20
India*	3.80	3.85	3.94	4.00

USDA (2012)
*emerging economies

remained stable or even reduced in some developed countries such as the USA, Canada and Russia.

Even though, world meat production has seen such a tremendous increase, there has not been any significant increase in the number of companies processing meat and meat products. Rather, as reported by Ollinger et al. (2005); the number of plants producing meat and meat products has decreased over the years while the number of employees needed to staff the remaining plants dropped by more than 20%. In China, Zhou et al. (2012) reported that, from 2000 to 2007, the number of enterprises involved in slaughtering and processing of meat decreased from 35 000 to 23 000 however the remaining companies became much larger in scale of operation. These changes have been attributed to technological development within the industry (Ollinger et al., 2005).

On the other hand, some experts believe that there is a potential for an end to the meat economy because of rising vegetarianism and the influence of the animal rights movement (Franklin, 1999; Maurer, 2002). However, environmental issues, including CO_2 emissions and water and land pollution together with water usage could play an important role. But as indicated by Zhou et al. (2012); the current developmental philosophy of fresh meat in the world's largest economy, China is 'stable development of the swine industry, active development of the poultry industry and fast development of the cattle and sheep industry'. The main purpose of this policy is indicated as to improve the balance of consumption and the demand structure of meat consumption in China. Will there ever by the end to the meat economy?

In many countries the meat industry forms the largest sector within the agricultural sector, which in itself is the largest sector of the national economy. The meat industry plays a major role in the economical development of any community and the nation's economy as a whole. Table 8.2 presents data on meat trade (export and import) of selected countries including the US, EU,

Table 8.2 Meat production and the meat trade (import and export) of selected countries

	(1000 metric tonnes)			
Country/Year	Production	Export	Import	Domestic Consumption
China				
2009	66,774	561	721	66,814
2010	69,226	708	767	69,235
2011	68,256	722	1059	68,583
United States				
2009	40,803	6,070	1,623	36,561
2010	41,322	6,292	1,491	36,467
2011	41,616	7,087	1,356	35,949
EU27				
2009	40,898	2,434	1,367	39,831
2010	41,767	3,156	1,242	39,853
2011	42,140	3,838	1,192	39,494
Brazil				
2009	23,554	5,459	36	18,131
2010	25,107	5,516	37	19,628
2011	25,625	5,283	42	20,384
Australia				
2009	3,243	1,434	187	1,972
2010	3,315	1,435	198	2,110
2011	3,426	1,484	193	2,145
Russia				
2009	5,395	16	2,899	8,278
2010	5,735	11	2,682	8,406
2011	6,020	40	2,609	8,589
India				
2009	5,064	610	0	4,454
2010	5,492	919	0	4,573
2011	6,070	1,230	0	4,840
Canada				
2009	4,219	1,775	565	3,015
2010	4,226	1,853	558	2,946
2011	4,126	1,803	625	2,950
New Zealand				
2009	671	514	48	205
2010	693	530	48	211
2011	651	503	50	198

USDA (2012)

China, India and Brazil. Which of these countries are prepared to lose the income generated from the meat trade to save the environment? A market survey conducted in the UK by the Agricultural and Horticultural Development Board (AHDB, 2012), reported that in 2011 the UK exported a total value of £1,048 million worth of red meat, with beef exports accounting for

£437 million, sheep meat exports £380 million and pig meat exports £231 million. On the other hand, the total value of meat imports in 2011 was 5% higher year on year at £2,664 million. Beef imports accounted for £855 million, sheep meat imports £411 million and pig meat imports £1,399 million (AHDB, 2012).

The meat industry also provides employment and that means a living for a vast majority of the population in many economies. As indicated by Leat et al. (2011); sustainability is three dimensional including economic, environmental and social segments. The economic and social segments can be said to be directly related, even though all three have some relations. Employment provided by the meat processing industry can therefore not be overlooked when discussing sustainability of the industry as it has a direct influence on the livelihood of employees and their families and the community as a whole. In the UK, 21% of those employed in the food and drink sector are employed in the meat industry. This make up to approximately 88 800 employed directly in the industry with a further 30 000 employed in the retail meat industry. In the United Stated, the American Meat Institute reported that in 2009 the meat and poultry packing and processing industry directly employed more than 500 000 workers with salary wages totalling $19 billion (AMI, 2011). On the other hand companies involved in meat production along with their suppliers, distributors, retailers and ancillary industries employed 6.2 million workers with job wages totalling $200 billion. The US meat industry contributes approximately 6% to GDP. It is worth mentioning that this aspect of the economy of any country is very important and can play a major role in decisions made in the development of the meat industry to become sustainable.

8.3 Sustainability issues in meat processing

Meat processing begins with the slaughter of the animal in slaughterhouses or abattoirs involving processes that lead to the production of fresh meat in the form of whole carcasses (poultry, pigs and lamb) or quarters (sides) as in the case of cattle. The basic processes that take place in the abattoirs are stunning and bleeding, hide or skin removal or treatment, evisceration, carcass dressing and washing. In some of the abattoirs, however, boning process in which finished carcasses are cut into retail portions may occur. During further or secondary processing, fresh meat is manufactured into products such as sausages, ham and bacon.

The processing of livestock and poultry into fresh meat and value added products for human consumption leads to the production of waste. Some of these wastes find themselves into the environment; into the atmosphere as greenhouse gases (GHG) or as various air pollutants, water bodies, increasing the biochemical oxygen demand (BOD) and thus affecting aquatic life. The World Bank Group indicates that the meat industry has the potential for generating large quantities of solid wastes and wastewater with a BOD of

600 milligrams per litre (mg/l). BOD can be as high as 8000 mg/l, or 10–20 kilograms per metric ton (kg/t) of slaughtered animal; and suspended solids levels can be 800 mg/l and higher (World Bank Group, 1999). In some cases, offensive odours may occur. However, the amounts of wastewater generated and the pollutant load depend on the kind of meat being processed.

As indicated previously, many experts have demonstrated the unsustainably high production and consumption of animal products in developed countries and Fiala (2006) indicated that the current meat production systems need to be reconsidered, and that governments and stakeholders must deal with a range of issues sooner rather than later to alleviate the problem. In the evaluation of the sustainability of the meat processing industry, matrices including the amount of Green House Gas (GHG) emissions, water usage and waste generation associated with the production of the various products, are utilized. The amount of GHG emissions, water usage and waste generation will however, depend on the size and scale of production of individual processing facility (Figure 8.1).

Considering the meat supply chain as a whole, from the farm to the table, the production of livestock and poultry as the raw material for the processing industry has been indicated to have the greatest impact on the environment. It is this stage of the production chain that has received concerns of many experts discussing the sustainability of the meat production industry. The FAO in 2006 reported that livestock production is one of the major causes of the world's most pressing environmental problems, including global warming, land degradation, air and water pollution, and loss of biodiversity. Fiala (2008) has reported that production processes for meat products have a significant impact on the environment, accounting for between 15% and 24% of current greenhouse

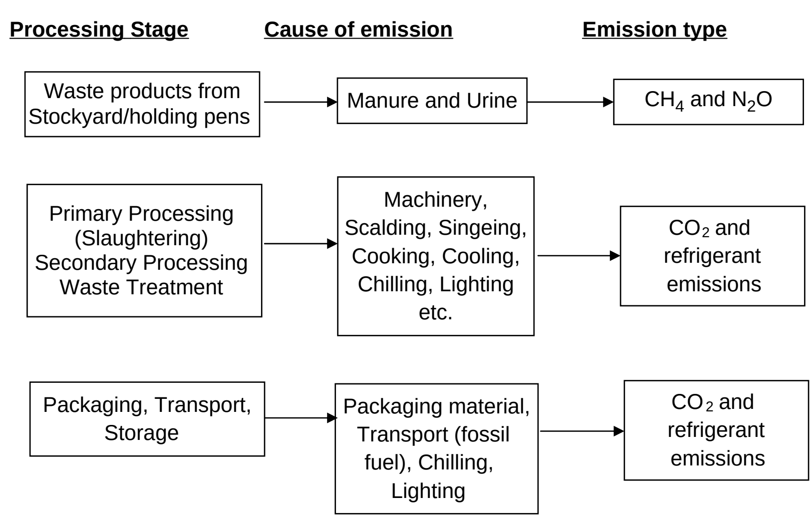

Figure 8.1 Meat processing and associated operations and greenhouse gases emissions. (Adopted from Garnett (2007)).

gas emissions. Meat processing on itself is been reported to produce only 3% of the world's greenhouse gas (GHG) emission (Scollan et al., 2010).

As mentioned above, the main issues of discussion in considering the sustainability of the meat industry or meat processing include water usage and wastewater management, greenhouse gas emissions and air pollution. However, other factors of consideration include food safety, health and safety, and nutritional health of the consumer. Discussion on the nutritional health is normally used to strengthen the argument on the environmental sustainability.

Primary processing of meat is identified as high water consumer and energy intensive. According to the Red Meat Abattoir Association (RMAA, 2012), 84% of water used in the red meat industry is discharged as wastewater containing high organic loads including suspended matter. Water is used for purposes including truck washing (after unloading animals), livestock washing, livestock watering, washing of carcasses, offal and casings, cooling and chilling, cleaning and sterilizing of equipment, cleaning floors, work surfaces, and workers' personal hygiene. Njezic and Okanovic (2010) reported a 500–1000 litres of water used in the slaughter of each cow or swine.

Wastewaters from slaughterhouses contain organic matter (including grease), suspended solids and inorganic material such as phosphates, nitrates, nitrites and salt. The main sources of these pollutants in the wastewater from meat processing are faeces, urine, blood, grease, washings from carcasses, floors and utensils, undigested food from the paunches of slaughtered animals, wastewater from the cooking, curing and pickling of meat and condensate from rendering of offal and other by-product processing. These wastes are generated at various stages during the slaughter of live animal and further processing of meat into various products. Wastewater quality is determined by the concentrations of organic matter present. This is expressed as the chemical oxygen demand (COD) or biological oxygen demand (oxygen required) during the process of decomposition over a five-day period (BOD_5). Table 8.3 shows the characteristics of wastewater generated from the slaughter of livestock and poultry.

Table 8.3 Characteristics of wastewater generated from livestock and poultry slaughter

Parameter (mg/l)	Pig[1]	Cattle[1]	Poultry[2]
BOD_5	1250	2000	1856
COD	2500	4000	–*
Suspended solids (SS)	700	1600	776
Total nitrogen	150	180	34
Total phosphorus	25	27	11
Oil and grease (fat)	150	270	1501

[1]Hansen and Mortenson (1992)
[2]US EPA (2004)
*Not reported

According to the FAO blood has the highest polluting value with a high BOD of 150 000–200 000 mg/l, and values may reach 405 000 mg/l. (Domestic wastewater has a BOD of 300 mg/l). Therefore if blood is discharged into water bodies without treatment, it could result in fast depletion of oxygen levels and subsequently affecting aquatic life.

Greenhouse gases generated from the utilization of energy from fossil fuel for various operations, waste treatment in anaerobic ponds within the meat industry is one of the issues considered in the discussions on the sustainability of meat processing. Wirsenius et al. (2011) iterated that, animal food products, such as meat, are characterized by high GHG emission intensities, with large divergences in emissions per food unit between different types of food product and argue that consumption taxes on animal products, including meat, differentiated by GHG emissions per food unit would change the average diet and could be a cost-effective policy for mitigating agricultural GHG emissions. In calculating the environmental effects of methane and CO_2 emissions of cattle, Subak (1999) indicated that, to produce 1 kg of beef requires the equivalent of 15 kg of CO_2. The US EPA in 2005 indicated that a gallon of gasoline emits approximately 2.4 kg of CO_2. Therefore in comparison, consuming 1 kg of beef has a similar effect on the environment as 6.25 gallons of gasoline, or driving an average American mid-size car 160 miles on the highway.

The slaughtering of livestock and poultry and the further processing of meat products involves the utilization of various forms of energy for various operations. Some of these operations include heating of water for scalding, singeing, cleaning, cooking, and the operation of various equipments such as cutting, chopping mixing and mincing machines. As indicated by Metz et al. (2001); in a report on climate change mitigation for the Intergovernmental Panel on Climate Change (IPCC), improvement of energy efficiency of industrial processes is the most significant option for lowering greenhouse gas emissions. The meat industry is therefore required to contribute to this reduction in greenhouse gas emissions by developing and using technologies that will make it energy efficient. Ramirez et al. in 2006, observed an increase in energy utilisation in the meat industry in four European countries including the Netherlands, France, United Kingdom and Germany. Two-thirds of this increase in energy utilization was reported to be due to strong hygiene regulations in these countries and not because of the increase in shares of the frozen and cut fresh meat market. This is also an indication of the role food safety and hygiene could play in sustainability, as associated with the meat industry, being the supplier of a high risk food. One aspect of sustainability which is becoming important is quality, food safety and nutritional/health. As indicated by Vandendriessche (2008); these factors are interrelated. The general perception and argument made by people

Table 8.4 Positive and negative nutrition and health aspects of consumption of processed meat

PRO
Rich in proteins
Low in sugar
High-grade proteins (sulphurous amino acids)
Pork fat = rich in unsaturated fatty acids
Vitamin B6/B12 (thiamine, riboflavin, cobalamine)
Vitamin C
Rich in absorbable haem Fe (red meat only)
Good source of Zn
Rich source of glutathione
CONTRA
Too rich in energy (fat) (except cooked ham and dry ham)
Too much salt (raw products) (dry ham and fermented sausage)
Low in fibre
Low in calcium
Biogenic amines (fermented products - fermented sausage)
Nitrosamines
Poly-aromatic carbohydrates (smoked products)

Vandendriessche (2008)

proposing an absolute meatless diet, in addition to the impact of meat processing on the environment, is that consumption is directly linked to diet related cardiovascular diseases, bone health and osteoporosis, body weight regulation, insulin sensitivity and diabetics. This is due to the fact that meat products contribute to the intake of salt and fat, and it is a poor source of calcium, which are directly linked to the above health conditions. Table 8.4 show the positive and negative nutrition and health aspects of the consumption of meat products.

Food safety of meat and meat products has become important in recent years. There has been a growing number of reported food poisoning cases associated or link to different types of meat and meat products. *Salmonella* and *Campylobacter* has been linked to outbreaks involving poultry and poultry products. *E. coli* O157 has been link to beef and beef products, specifically beef burgers. Other pathogens linked to meat products include *Listeria monocytogenes* and *E. coli* O104 H4, which was responsible for one of the recent food poisoning outbreaks which affected many countries in Europe in 2011. Apart from microorganisms, chemical safety of food has also made an impact in the discussion of sustainability of the industry. Dioxin is one of the commonest chemical toxins that have been reported. It is therefore important to consider these factors in the discussion of the sustainability of the meat industry.

8.3.1 Primary processing of livestock

The basic steps in the slaughtering process of livestock and waste generated is shown in Figure 8.2 . Kroyer (1995) classified waste from the meat industry into three categories including:

a) stockyard waste;
b) slaughterhouse waste;
c) packaging house waste.

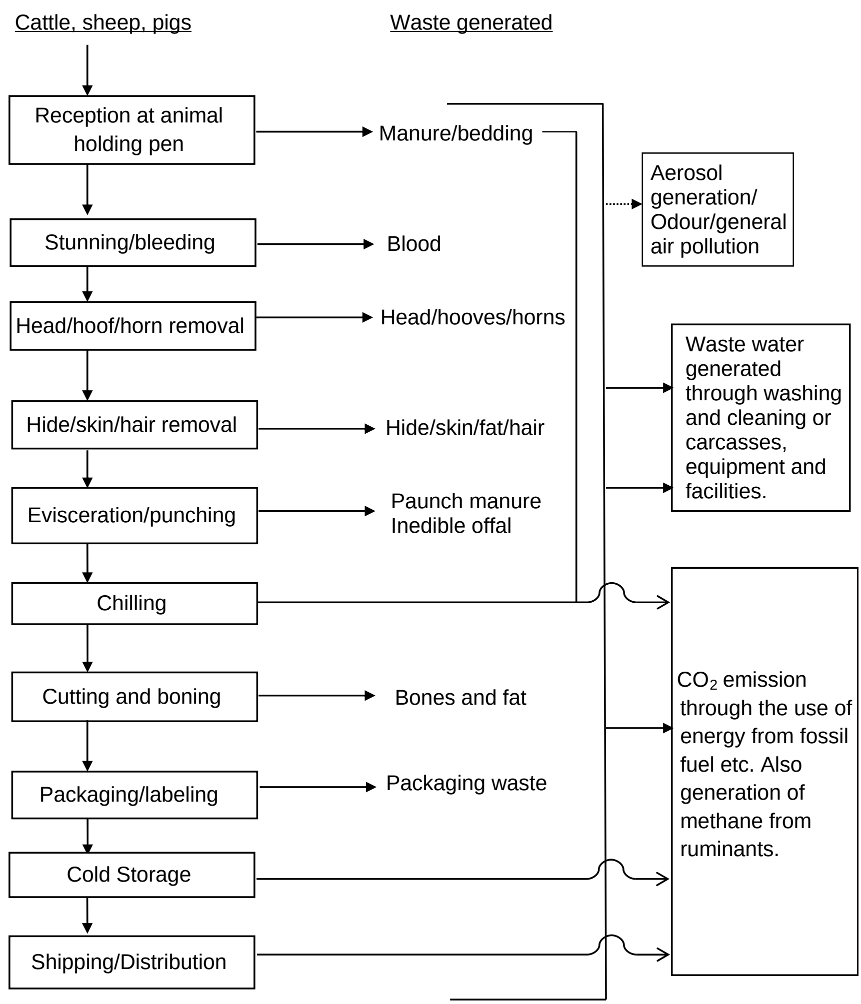

Figure 8.2 Flow diagrams of livestock slaughter and waste generation.

The main waste generated during the slaughter of livestock is wastewater containing blood, solids such as meat, skin trimmings, hair, bone chips (powder), hooves and grease (fat – scum).

8.3.1.1 Animal reception Live animals including cattle, sheep or pigs are delivered to the abattoir in trucks and unloaded into the stockyard or holding pens. Here the animals are rested for a day or two before slaughter. The animals are watered and provided with bedding. Before they are slaughtered the animals may be washed to remove any dirt that may be present on their body. Major waste generated here may include manure, urine and wastewater. The result of this process is the emission of methane and nitric oxide and CO_2 through the use of electricity for lighting and ventilation. The animal reception stage is reported to contribute about 13% of the wastewater volume and about 7% of the COD load in terms of the final wastewater (RMAA, 2012).

8.3.1.2 Stunning and bleeding Stunning is the process through which animals are rendered unconscious before decapitation to effect bleeding. Except in ritual slaughter, animals are anaesthetized before bleeding. The primary aim of stunning is of welfare origin. It to render the animal instantaneously insensible to any pain and feelings of distress and to ensure that it remains insensible to pain until it is dead. Stunning is achieved through the using of a bolt pistol or electric shock depending on the animal type. They are then shackled by a hind leg and hoisted onto an overhead rail or dressing trolley. Bleeding, or sticking, then takes place, with the blood collected in a trough for disposal or for further processing or the blood may be allowed to drain through the general waste drains. Blood accounts for approximately 4% of the liveweight of the animal.

8.3.1.3 Dressing, evisceration, cutting and boning Dressing involves the separation of the head, feet, hide (in the case of sheep, goats and cattle), excess fat, viscera and offal (edible and inedible) from the bones and edible muscular tissue. Offal processing is reported to contribute approximately 39% of the wastewater volume and about 68% of the COD load in terms of the final wastewater (RMAA, 2012). In cattle, sheep and goats the head and hoofs are removed. The head is cleaned with water, and the tongue and brain are recovered. Hides are then removed for further processing where they are preserved by salting or chilled on ice. In the case of pigs, hair is removed from the carcasses by scalding in hot water followed by scraping. Carcasses are then singed to remove any remaining hair. The carcasses are then split opened through the abdominal wall to remove the viscera. Manure is removed from the stomach (paunch) and intestines and then cleaned in preparation for further processing. The FAO estimates the paunch contents, ‘paunch manure’ (partially digested feed), to range from 27 to 40 kg and indicates four methods of handling the paunch.

1. Total dumping: All of the paunch contents are flushed away into the sewer.
2. Wet dumping: The paunch contents are washed out and the wet slurry is screened from the presence of gross solids, which are subsequently removed.
3. Dry dumping: The paunch contents are dumped for subsequent rendering or for disposal as solid waste without needless water flushing.
4. Whole paunch handling: The entire paunch may be removed, intact, for rendering or for disposal as solid waste.

Edible offal (tongue, lungs, heart and liver) is separated, washed and chilled. The carcasses are then split, rinsed and then conveyed to a cold storage area for rapid chilling. Cattle and pig carcasses, but not sheep and goats, are split along the mid ventral axis into two sides. In cattle each half can further be cut into two at the 7th cervical vertebrae, the 13th rib and along the ventral edge of the vertebrae.

Carcass cutting and boning often take place after chilling, since a carcass is easier to handle and cut when it is chilled. Boning is the term used to describe the process of cutting meat away from the bone. Recent developments in processing technology have made it possible to undertake boning while the carcass is still warm, eliminating the need to chill the carcass at this stage in the process. This is referred to as 'hot boning'. Waste generated during the process of boning includes bones as greater proportion and fat trimmings, most of which make end up in landfills (Kupusovic et al., 2007). It is reported that the slaughter process of livestock generates about 27% of the wastewater volume and about 15% of the COD load in terms of the final wastewater (RMAA, 2012).

8.3.2 Primary processing of poultry

The primary processing of poultry consists of a number of stages which follow each other in a strict sequence. These are separated in the factory for reasons of hygienic and manageable length and each step entails a specific task which has to be performed effectively. The aim is to remove blood, feathers, legs, head and offal in a hygienic manner and to chill the carcass as rapidly as possible without compromising quality. Poultry processing is reported to require large amounts of high quality water. This use of water take place right from when live birds are received to chilling and cleaning of premises and equipment used in the slaughter process. Process waste water may contain high levels of nitrogen (protein), phosphorus, residual chemicals such as chlorine from sanitizers and disinfectants used in cleaning and disinfections.

Primary processing can be divided into:

1. Killing line.
2. Evisceration (EV) line.
3. Chilling line.

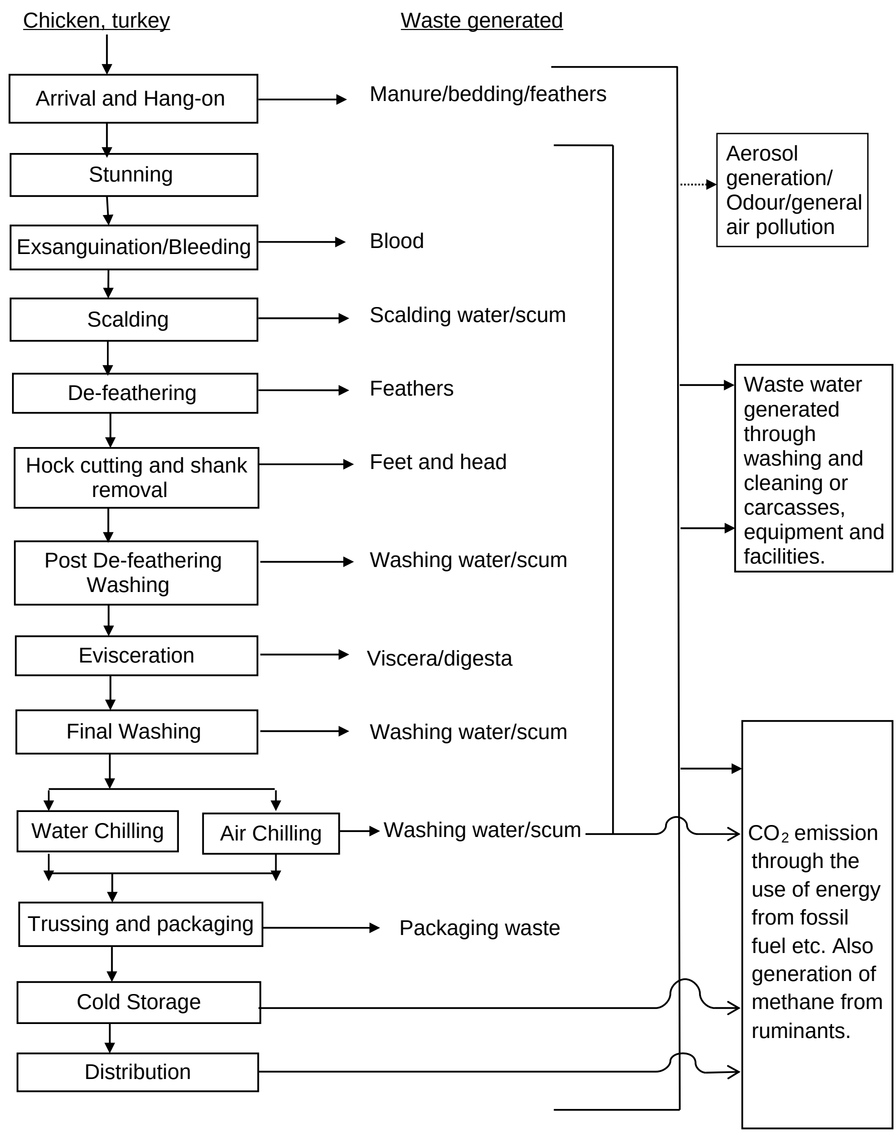

Figure 8.3 Flow diagram of poultry slaughter and waste generation.

During these operations of poultry processing or slaughter a number of wastes are generated which has the potential of ending up in the environment including the atmosphere as aerosols, landfill sites, water bodies and so on, depending on the pre-treatment of this waste before discharge it may become pollutants in the environment or useful materials. Figure 8.3 presents the various steps involve in processing of poultry from the time of arrival at the plant to distribution and the various waste generated at each stage.

8.3.2.1 Arrival and hang-on Williams (not dated) indicated the main slaughterhouse waste from poultry processing which includes processing water and organic solid by-products irrespective of the processing scale. In addition to waste generation the sitting of processing plants (particularly large-scale size plants), must consider the biosecurity and near neighbour issues in discussing the subject of sustainability.

8.3.2.2 Animal reception, stunning and bleeding Live birds are received in crates on trucks and unloaded directly onto a conveyor to begin the slaughtering process. The main waste at this point includes manure, feathers, beddings, waste water (due to cleaning) and sometimes dead animals. There is the possibility that the waste generated at the stage could lead to contamination of water bodies if allowed to drain untreated. Some of these water bodies could become reservoirs for these pathogens that may re-infect the food chain in the future.

Stunning basically involve the rendering of animals unconscious before exsanguination and subsequent bleeding to remove as much blood as possible. The most common and simplest practice of stunning is the use of electrical current. The bird is hung by the feet and the head comes in contact with water in a holding container charged with electrical current flowing to it. The current flows through the bird to the shackle line that serves as the grounding. Approximately 1% of NaCl is sometimes added to the water used in this process.

Bleeding immediately follows stunning. This is achieved by the use of automatic killers which severe the back or side of the neck. During the bleeding stage the bird loses about 30–50% of its blood (Sams and McKee, 2010). It is estimated that about 2–4% of the live weight of the bird is lost as blood (Sams and McKee, 2010; Williams, nd). The blood is collected in a tank and treated as animal by-product to be used for other products such as animal and fish feed or fertilizer. However, as indicated above, blood has the highest polluting value with a high BOD and if not handled efficiently, leakage or deliberate discharge into water systems could lead to detrimental environmental impacts.

8.3.2.3 Scalding and defeathering The scalding and defeathering process of poultry slaughtering is one of a single step where large amounts of water are utilized and wastewater is generated. In addition to the wastewater generation, there is also a greater amount of aerosols produced. However, the amount of wastewater generation may vary substantially among processing plants (Jayathilakan et al., 2012). The main objective of scalding is to loosen the feathers for ease of removal in the defeathering machine. It therefore involves the use of hot water which is heated using electrical energy or energy from fossil fuel. Approximately 7–10% of the live body weight of slaughtered birds comprise of feathers (Williams, nd).

Deafethering is a major source of cross-contamination. One contaminated bird contaminates at least 200 following birds. The defeathering machine scatter organisms in the form of water splash and the pluckers (rubber fingers) are difficult to clean. The pluckers also cause aerosols and disseminate organisms through the air. Damaged plucker fingers with cracks can harbour microorganisms which multiply. As it is difficult to clean them, relatively chlorine resistance strains of *Staphylococcus aureus* have been found in plucker fingers. This could be a major food safety issue and as indicated before processes applied in order to meet food safety and hygiene regulations involves the expenditure of energy which contributes to greenhouse gases (Ramirez et al., 2006).

8.3.2.4 Evisceration and final washing Carcasses are re-hung on the evisceration line using clean shackles. The evisceration area is normally physically separated from the defeathering area. This is to avoid further contamination through aerosol generated within the defeathering area. The major waste generated at this stage is wastewater and scum from the extensive washing of the carcass and cleaning of offal. The evisceration machine also uses electrical energy during its operation and contributes to greenhouse gas emission.

The end of slaughtering of both poultry and other livestock is the cooling or chilled storage. Poultry chilling may be achieved either through water chilling or air chilling. Water chilling usually involves various stages including pre-chilling and chilling. This involves the use of large tanks containing large quantities of water at chilled temperature (7–12 °C for the pre-chiller and 1–4 °C for the chiller). Carcasses are propelled through the system by means of an auger system or some form of a paddle. At the end of the day's slaughter or at various time intervals of operations the water used in the chilling process has to be disposed as wastewater. Such wastewater may contain some amount of grease and suspended solids.

Packaging of the end products of slaughtering can also lead to generation of solid waste. These may end up in landfill sites causing significant environmental pollution.

8.3.3 Secondary meat processing

Secondary processing of meat includes a variety of operations amongst which grinding, mixing with additives, curing, pickling, smoking, cooking and canning form the major operations. The edible portion of carcasses from slaughtering and cutting may be processed in a variety of ways into various products including the manufacturing of many varieties of sausages, hams, bacon, canned meats, pickled meats, hamburger, portioned cuts, and so on.

There are various reasons for meat processing including the following from both the manufactures' and consumers' perspectives:

1. Manufacturer's perspective
   a) Better utilization of carcass meat; after the removal of the more expensive cuts from the carcass, approximately 70% of the carcass is left. These lower grade cuts (often high in fat and connective tissue) are used.
   b) Upgrading off-cuts (added value using low grade trimmings).
2. Consumer's perspective
   a) Convenience (relatively ready to cook).
   b) Variety of products available.
   c) Portion control (consumer can purchase parts required).
   d) Consistent product quality.

Most meat products are made from relatively low-grade meat, high in fat and connective tissue. This ensures better utilization of carcass meats and satisfies consumers' demands for convenience, variety and quality.

Dukic and Okanavic (2011) indicated some of the specific operations involved in meat processing such as washing raw materials, thawing, fragmentation (cutting, grinding, chopping), mixing, salting, drying, cooking/baking, pasteurization/sterilization, cooling, packaging and cleaning and disinfection of processing equipment and premises, just to mention a few. Most of these operations lead to the generation of waste which if not controlled could result in the pollution of the environment. The use of electricity to run most of the equipment in these operations also contributes to the greenhouse emissions.

Manufacture of the various products involves the use of various additives. Common salt and a range of chemicals for curing, smoking and preservation and colouring are used. Among these preservatives are sulphur dioxide, potassium nitrate (for pickling), sodium nitrate (a meat colour fixative during curing) and sodium nitrite (for curing, colouring and preserving) and sodium polyphosphates. Most of these chemicals are washed off into wastewater and may enter water bodies causing various levels of pollutions.

As indicated by Dukic and Okanavic (2011); environmental impact of the secondary meat processing industry (as in the case of primary processing) is reflected in water usage, wastewater discharge, energy consumption and solid waste generation, with wastewater generation having the greatest impact. Water usage in meat processing is reported to range between 10–20 m^3/t and the amount of wastewater generated ranging between 10–25 m^3/tonne of processed meat (World Bank Group, 1999). However, it is also indicated that the quantities of water usage varies depending on the type of meat products manufactured. Washing and defrosting was recognized as the stages of meat processing operations that utilizes the greatest amount of water consisting of 3–5 m^3/tonne (Dukic and Okanavic, 2011). Other stages of

Table 8.5 Water usage and wastewater generation from the production of salami and sausages

Parameter	Salami	Sausages
Water usage, m^3/t	7.5	10
BOD in wastewater, kg/t	4.7	8–10
Nitrogen in wastewater g/l	300	–
Phosphorus in wastewater g/l	140	–

Dukic and Okanavic (2011)

meat processing identified as using significant quantities of water include pasteurization, sterilization, cooling, cleaning and sanitation. Table 8.5 show water usage and the characteristics of wastewater generated in the manufacture of salami and sausages.

Curing and smoking are two sets of operations in meat processing that almost all the time go together. The process of curing and smoking can lead to significant environmental pollution. The curing process involves the injection of salt and sugar solutions into the meat, usually with a single needle or multi-needle injection machine depending on the scale of production. Some curing is also done by soaking the meat in the curing solution. Majority of the products that are cured may also end up being smoked. Smoking is achieved in smokehouses operated using wood chips or sawdust to generate smoke at elevated temperatures, or smoked flavours are developed by soaking meat in a 'liquid smoke' solution or injecting this solution into the meat. Smoke generated during these operations contains components that can be harmful to human health. Some of these components include phenols, nitrite, N-nitrosated components, polycyclic aromatic hydrocarbons and CO (Andree et al., 2010; Dukic and Okanavic, 2011). As indicated by the World Bank Group, Smoking operations can release toxic organic compounds into the air and chloride levels from curing and pickling may be very high – up to 77 000 mg/l, which if discharge into water bodies may lead to devastating effects on aquatic life. Dukic and Okanavic reported that for a one (1) ton of smoked product produced, 0.3 kg CO, 0.15 kg inorganic particles and 0.2 kg total organic carbon is emitted into the atmosphere and soot and tar compounds from the walls of smoking chamber ends up in wastewater after cleaning. Njezic and Okanovic (2009) reported a total of 30–35 kg of solid waste generated per ton of product produced by a typical Italian company producing salami and ham.

In general, there are two forms of energy requirements for secondary meat processing. Thermal energy is used for cooking, pasteurization, sterilization and smoking. Electrical energy is utilized in cooling, freezing and cleaning, and may be used to generate the thermal energy use for the above operations. This means through these operations, there is significant contribution to greenhouse gas generation.

8.4 Sustainable meat processing and future opportunities

Sustainability development has been defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WECD, 1987). As indicated before sustainable development consists of a three-dimensional interrelated segment including economic, environmental and social dimensions (Leat et al., 2011). Leat et al. further gave examples of the economic dimension as relating to the efficient uses of resources, competitiveness and viability of the food sector as well as its contributions to society; the environmental dimension relating to the management of natural resources with a view to ensuring that they are available in the future, protection of landscapes, habitats, biodiversity, as well as the quality of drinking water and air, and the social dimension relating labour opportunities, community development and human welfare. It therefore implies that for the meat processing industry to become sustainable it has to meet or have policies and strategic plans to achieve economic, environmental and social sustainability.

For the meat processing industry to be sustainable, policy and strategies developed must aim at achieving the following:

1. Reducing wastewater quantities.
2. Reducing the risks of emissions (waste and greenhouse gases) into the atmosphere and water.
3. Reducing pollutant (solid and liquid) into the environment (air and water) bodies.
4. Increased usage of slaughterhouse by-products and processing waste.
5. Efficiency in waste treatment.
6. Providing labour opportunities, community development and human welfare.

The Australian Industry Group indicates the benefits of improving waste management in abattoirs and meat processing facilities as follows:

1. Reducing the cost of purchasing chemicals and other materials through improved efficiency and less spoilage.
2. Minimizing waste treatment and disposal costs (and possibly generating alternative income streams for recyclable products).
3. Reducing environmental impacts associated with waste disposal and consumption of raw materials and other resources.
4. Improving the reputation of the meat processing business and employee satisfaction through promoting an environmentally responsible image.
5. Providing a safer workplace through process improvement and less waste handling.

According to Luste and Luostarinen (2010); efficient waste management is increasingly required due to several environmental and economical concerns such as climate change, eutrophication, and the diminishing resources for fossil energy and raw materials.

Energy, in the form of electrical and thermal, is used in the slaughter and meat processing for various operations. Some of the operations include the use for compressors in refrigeration and freezing plants, air compressors and different types of conveyor equipment, mixing, mincing (grinding), chopping, and flaking equipments, in running steam boilers to produce process steam, warm, hot and tap water as well as comfort heating (Fritzson and Berntsson, 2006a). Even though the meat processing industry is known to relatively use smaller amount of energy compared to other industries, becoming energy efficient is reported to be profitable to slaughter and meat processing plants, especially as energy prices rise (Fritzson and Berntsson, 2006a). In current years, the number of slaughter and meat processing plants is decreasing while the sizes of individual plants are becoming larger. It is indicated that the increase in the size of plants could result in an increase in the potential to saving energy and thereby decreasing CO_2 emission associated to the use of energy in slaughter and meat processing plants (Fritzson and Berntsson, 2006a). Fritzson and Berntsson (2006b) reported that the slaughter and meat processing industry can achieve energy efficiency and identified opportunities for process integration that could contribute to this achievement.

To achieve the social dimension aspect of sustainability the operations of the meat processing industry will have to be socially acceptable as to the working circumstances and conditions of employees, while they share in profits and participate in decision making (Wognum et al., 2011). The World Bank Group (2007) provides detailed and useful environmental health and safety guidelines for all steps of poultry processing, from the reception of live birds, through slaughter and evisceration, to simple waste processing. Manufacturers would also have to make sure products manufactured are safe for human consumption and does not contain any hazardous substances. As indicated by Wognum et al. (2011); industry must take measures to safeguard consumers against any food hazards, hence, the need to embed the measures in an international institutional context. This is important as consumers demand a wide choice of fresh and processed products which have become increasingly internationally sourced and transported over long distances and times.

In view of all these the sustainability of the meat industry has come to the forefront through the voice of activists, some of whom call for a complete ban on the consumption of meat. It is indicated that even though vegetarianism is increasing, there is no corresponding decrease in meat consumption. Rather, the general observation is that there is some decrease of meat consumption in the industrialized nations while the increase in consumption has turned to the developing nations. The same pattern is observed for meat production. For instance the demand for meat and meat products in China is expected to rise as

average income and expenditure increases along with urbanization and population growth in the years to come (Meng et al., 2011; Zhang and Xu, 2008). The future goal of China for the meat industry for 2015 is reviewed by Zhou et al. (2012). Stehfest et al. (2009) has iterated that a global transition towards low-meat diets, which is desirable for health reasons, may reduce the costs of climate change mitigation by as much as 50% in 2050. In the Western world one of the main goals suggested to promote sustainability of the meat industry is partial substitution of proteins of animal origin by plant proteins (Aiking, 2011; Gerbens-Leenes et al., 2010) and as indicated by Schösler et al. (2012), the preferences of the younger generation could pave the way for the development of new meal patterns, in particular combined meal formats, which may reduce the special status of meat and make substitution of animal protein in diets easier, thus reducing the reliance on animal protein.

Vinnari (2008) suggested the following strategies that can be used to help decrease meat consumption:

1. Aid the technological development of products that could replace foodstuffs that originate from animals.
2. Use advertisement campaigns to increase consumer knowledge about animal rights and vegetarianism.
3. Make political decisions to transfer agricultural production away from meat production and promote the broadening of the selection of alternatives to meat products in stores.
4. Place higher taxes on meat products.

While some experts suggest partial substitution of meat in diets others propose a complete ban to meat consumption. It is clear that reduced production and consumption of foods from animal sources in high-consumption populations will contribute to drastic reduction in greenhouse gases (FAO, 2006; McMichael et al., 2007; Smith et al., 2007) and this has been proposed as a strategy towards the sustainability achievement of the livestock and meat industry. However, as iterated by Biesalski (2005); taking together meat is an important nutrient for human health and development and therefore as an essential part of a mixed diet, meat ensures adequate delivery of essential micronutrients and amino acids and is involved in regulatory processes of energy metabolism. As data from literature show, it does not seem quite possible to achieve complete elimination of meat from our diets. As indicated by de Boer et al. (2007), the aim of sustainability may require that people in Western countries choose to eat smaller quantities of meat as well as types of meat that are produced in a more responsible way. The literature shows that meat production and consumption will continue to increase as population, urbanization and income grows (Elam, 2006; Roppa, 2010; OECD, 2012). This increase, however, is projected to occur in the emerging markets including China, Brazil and India with Russia also seeing some growth.

In many countries there has been the development of strategies towards sustainable development of the meat industry. Governments, together with the meat industry and other stakeholders, have several initiated themes and technological development directed towards sustainability.

One of the main concepts proposed is the Cleaner Production (CP) concept. Cleaner Production is defined by COWI (2008) as the continuous application of an integrated, preventive, environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment. It is indicated to be different to the traditional 'pollution control' approach to environmental management, which mainly involves pollution control as an after-the-event, 'react and treat' approach, Cleaner Production being a proactive, 'anticipate and prevent' philosophy.

Cleaner production in the meat industry takes care of all the components of industry including those directly connected to primary and secondary processing and support industry (logistics, wholesalers, retailers, etc.). It is reported to cater for the following during the life cycle of the products (COWI, 2008):

- Production processes: Cleaner Production involves the conservation of raw materials and energy, the elimination of toxic raw materials, and the reduction in the quantities and toxicity of wastes and emissions.
- Product development and design: Cleaner Production involves the reduction of negative impacts throughout the life cycle of the product: from raw material extraction to ultimate disposal.
- Service industries: Cleaner Production involves the incorporation of environmental considerations into the design and delivery of services.

A recent development towards sustainability in the meat industry and research into the exploration of alternative methods of meat production, experts has developed methods involving tissue engineering techniques to produce meat *in vitro*. This type of meat is referred to as 'cultured meat' which is being developed as a potentially healthier and more efficient alternative to conventional meat. As indicated by the researchers (Tuomisto and de Mattos, 2011), production of 1000 kg cultured meat requires 26–33 GJ energy, 367–521 m^3 water, 190–230 m^2 land, and emits 1900–2240 kg CO_2–eq GHG emissions. Compared to conventionally produced meat, 7–45% lower energy was used to produce cultured meat, 78–96% lower GHG produced, 99% lower land used, and 82–96% less water was used, however these was found to depend on the product compared. The authors also attached a greater uncertainty to this type of product meaning there is a long way to realize any appreciable acceptability of the product. Before such product is introduced to the market, there is the need to evaluate it safety for human consumption.

It is worth mentioning that meat industry faces a lot of pressure to achieve sustainability. This pressure is compounded by the high input cost of the industry. However, for the industry to survive this pressure, there is the need to develop processes that involve responsible management of raw materials and energy, elimination of toxic raw materials, reduction in the quantities and toxicity of wastes and emissions generated as a result of its operations. This is more important as the demand for meat and meat products is projected to continue to increase with no indication of plummeting in the foreseeable future.

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9
Seafood Processing

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9.1 Introduction

The term 'seafood' as used in this chapter includes finfish, shellfish and crustaceans in fresh, frozen and processed product forms. Seafood satisfies a significant portion of global food demand: 92 million tonnes of fish were landed by capture fisheries in 2006, of which approximately 77% was destined for human consumption (FAO, 2009). This accounts for approximately 15% of the world's animal protein supply (FAO, 2009). The global seafood market is estimated at US$ 100 billion per annum with the world demand for seafood increasing by 3% per year (World Nutrition Forum, 2006). The top five consumed species are salmon, shrimp, tilapia, catfish and crab.

Traditionally, concerns regarding the sustainable development of seafood production have been mainly focused on the biological impact on target and by-catch stocks, as well as ecosystem effects of certain types of fishing gear (Winther et al., 2009). Increasingly attention is also being paid to the environmental and carbon impact of the resources used to catch/raise, process and distribute seafood products and the resulting emissions to air, water and ground. The use of fossil fuels, particularly diesel, during fishing has been identified as a large contributor to the overall carbon footprint of fishing operations (Ziegler et al., 2003; Winther et al., 2009). For farmed fish, such as salmon, feed production dominates the carbon footprint (Winther et al., 2009). In relation specifically to seafood processing, from a sustainable development approach four areas have been recognized as important in the analysis of sustainability: energy usage, water usage, effluents and by-product development (Hall, 2011). Within the processing

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sector cannery operations and transportation by air are often identified as the other major contributors to the overall carbon footprint (Winther et al., 2009; Tan and Culaba, 2009).

Van den Burg et al. (2012) state that the energy used in the production of plaice and cod is higher than that for beef, pork and chicken. However, the Global Warming Potential (GWP) of plaice and cod is comparable to the GWP of pork and chicken and lower than the GWP of beef.

Unlike other sectors of the food industry, as Iles (2007) argues, most processors within seafood chains are not known to the public, or do not have brands or reputations that consumers and citizens are aware of. Retailers and restaurant chains are much better known. This lack of focus on production may lead to a lack of focus on the role of processing in creating a more sustainable seafood production chain.

9.2 Sustainable seafood products and their processing

As already mentioned energy usage, water usage, effluents and by-product development are the four key topics in seafood sustainability.

How these areas are analysed and where the boundaries for such assessments are placed, make comparing the results and conclusions of different studies and prioritizing the relative importance of different life cycle stages very difficult. The two main approaches to such assessments are: Carbon Foot-printing (CF) and Life Cycle Assessment (LCA). Carbon Foot-printing (CF) involves the estimate of the overall amount of GHG emissions associated with a product (i.e. any good or service) along its supply chain, even including use and end-of-life recovery and disposal (EPLCA, 2007). Life Cycle Assessment (LCA) is an internationally standardized technique (ISO, 2006a,b) which makes the evaluation of the environmental impact of a product through its entire life cycle possible. A common criteria is to calculate various greenhouse gas emissions to describe total contributions to climate change in terms of kilograms of CO_2 equivalent. However, other impact categories include acidification and eutrophication potentials, abiotic resource use, cumulative energy demand and biotic resource use (Fulton, 2010).

Throughout the processing chain from harvest to final consumption there is a dearth of real data on energy/water usage, effluent production and by-product development. Catching and farming of seafood represent a considerable carbon investment, while finding useful uses for fish waste is important to improve the overall environmental impact of seafood production, it is equally important to reduce the generation of waste, by improving processing yields, and extending the high quality shelf-life of such products to ensure that as much as possible is consumed and not wasted.

9.2.1 Processing operations

Throughout the seafood production and distribution chain there are a series of processing operations from initial catch to final cooking and consumption that use energy and water and produce effluent and waste.

9.2.1.1 Catching and primary chilling The first stage of the production chain for wild and farmed seafood is the catching operation. Usually the seafood will be chilled on the boat immediately after catching or within a few hours.

The use of fossil fuels, particularly diesel, during fishing has been identified as a large contributor to the overall carbon footprint of fishing operations (Winther et al., 2009; Ziegler et al., 2003). A number of studies have calculated that the fish harvesting stage of the production cycle typically accounts for 70–95% of the total impact, regardless of the impact category considered (Ziegler et al., 2003; Thrane, 2004; Hospido et al., 2006). However, Fulton (2010) reported that the percentage of the global warming potential due to fishing varied markedly between fishing systems and species with figures of 22 to 80% for cod fillets, 10 to 57% for pollock and 25 to 36% for pink salmon, all delivered to Grimsby in the UK. For farmed fish, such as salmon, feed production dominates the carbon footprint (Winther et al., 2009). There appears to be considerable differences in the energy used in fishing (Table 9.1) with more recent studies generally reporting far less energy use.

Primary chilling is the most important stage of the fish processing chain. The rate of temperature reduction determines the subsequent safety and quality of the fish. The total amount of heat to be extracted is dependent on the type of fish, its initial temperature (which will be dictated by the water temperature), the final temperature to which the fish is required to be cooled to prior to storage (which for most fish will be 0°C), and the mass of the fish that is being cooled.

Ice is used extensively throughout the world to chill and store fish during harvesting. Ice keeps the fish fresh and wet at a low temperature without having to use monitoring devices such as thermostats. Ice has the advantage of being able to deliver a large amount of refrigeration in a short time as well as maintaining a very constant temperature, 0°C to −0.5°C (where sea water is present). Many small and medium sized fishing vessels have no active refrigeration systems and simply take the amount of ice they estimate they will require for their trip. While the lack of a refrigeration system offers some immediate energy savings, the extra weight of the ice will increase the energy used for transport. However, if not enough ice is brought onboard, or there is a delay in landing, the fish catch may not arrive to its destination in optimal conditions, or even worse the catch may not be fit for sale and hence go to waste, entailing both economical and environmental repercussions. Onboard mechanical compression powered ice makers are commonly used on larger fishing vessels. However, such systems have high capital costs and high running

Table 9.1 Energy performance of industrial fisheries

Type of fish	Fishery location	Time frame	Type of vessel/gear	Fuel use (l/tonne live weight)	Source
Alaskan pollock	US waters (Bering sea)	2008	Trawler	36	Fulton (2010)
Alaskan pollock	US waters (Bering sea)	2008	Catcher-processor	101	Fulton (2010)
Redfish spp.	North Atlantic	Late 1990s	Trawl	420	Tyedmers (2001)
Cod/flatfish spp.	North Atlantic	Late 1990s	Danish seine	440	Tyedmers (2001)
Cod/haddock	North Atlantic	Late 1990s	Longline	490	Tyedmers (2001)
Cod/saithe	North Atlantic	Late 1990s	Trawl	530	Tyedmers (2001)
Flatfish spp.	NE Atlantic	Late 1990s	Trawl	2300	Tyedmers (2001)
Herring/mackerel	NE Atlantic	Late 1990s	Purse seine	100	Tyedmers (2001)
Herring/saithe	NE Atlantic	Late 1990s	Danish Seine	140	Tyedmers (2001)
Swordfish/tuna	NW Atlantic	Late 1990s	Longline	1740	Tyedmers (2001)
Crab	NW Atlantic	Late 1990s	Trap	330	Tyedmers (2001)
Scallop	North Atlantic	Late 1990s	Dredge	350	Tyedmers (2001)
Shrimp	North Atlantic	Late 1990s	Trawl	920	Tyedmers (2001)
Norway lobster	NE Atlantic	Late 1990s	Trawl	1030	Tyedmers (2001)
Shrimp	SW Pacific	Late 1990s	Trawl	3000	Tyedmers (2004)
Salmon spp.	NE Pacific	1990s	Purse seine	360	Tyedmers (2000)
Salmon spp.	NE Pacific	1990s	Gillnet	810	Tyedmers (2000)
Salmon spp.	NE Pacific	1990s	Troll	830	Tyedmers (2000)
Herring	NE Pacific	Early 1990s	Purse seine	140	Tyedmers (2000)
Swordfish/tuna	Central Pacific	Early 1990s	Longline	2200	Tyedmers (2004)
Alaskan pollock	North Pacific	Early 1980s	Trawler	580–2310	Watanabe & Uchida (1984)
Alaskan pollock	North Pacific	Early 1980s	Catcher-processor	600	Watanabe & Okubo (1989)
Salmon spp.	NW Pacific	Early 1980s	Trap	780	Watanabe & Okubo (1989)
Flatfish spp.	NW Pacific	Early 1980s	Trawl	750	Watanabe & Okubo (1989)

Croakers	NW Pacific	Early 1980s	Trawl	1500	Watanabe & Okubo (1989)
Herring	NW Pacific	Early 1980s	Purse seine	1000	Watanabe & Okubo (1989)
Skipjack/tuna	Pacific	Early 1980s	Pole and line	1400	Watanabe & Okubo (1989)
Skipjack/tuna	Pacific	Early 1980s	Purse seine	1500	Watanabe & Okubo (1989)
Salmon spp.	NW Pacific	Early 1980s	Gillnet	1800	Watanabe & Okubo (1989)
Tuna/billfish	Pacific	Early 1980s	Longline	3400	Watanabe & Okubo (1989)
Abalone/clams	NW Pacific	Early 1980s	Hand gathering	300	Watanabe & Okubo (1989)
Shrimp	North Pacific	Early 1980s	Trawl	960	Watanabe & Okubo (1989)
Crab	NW Pacific	Early 1980s	Trap	1300	Watanabe & Okubo (1989)
Spiny lobster	NW Pacific	Early 1980s	Trawl	1600	Watanabe & Okubo (1989)
Squid	NW Pacific	Early 1980s	Jig	1700	Watanabe & Okubo (1989)
Alaskan pollock	North Pacific	1975	Trawler	200	Nomura (1980)

Table 9.2 Energy required to manufacture ice kWh/tonne (Graham 1975. © Crown copyright 1975)

	Energy (kWh/tonne)	
Type of ice	Temperate area	Tropical area
Flake	50–60	70–85
Tube	40–50	55–70
Block	40–50	55–70

costs (increase in fuel costs) and are bulky, for example a typical commercially available ice generating machine producing 6 tonnes of flaked ice/day could use 15 kW and weigh around 1000 kg (Clavell, 2007) and are thus, not well suited, to the needs and budgets of small to medium sized fishing vessels.

The energy required to make a tonne of ice is not constant. It varies widely depending on a number of factors (Graham, 1975), the most important of which are: 1) type of icemaker, 2) operating temperature, 3) make-up water temperature, 4) cooling water temperature, 5) air temperature, 6) size of plant, 7) utilization of plant and 8) method of refrigeration.

There is very little published data on the energy required to manufacture ice. The values given in Table 9.2 show how energy requirements can increase considerably in warm climates. This data was quoted in a 1975 Torry report by Graham (1975). The same figures were also quoted by a 1992 revised WHO report by Graham et al. (1992). The values in Table 9.2 are for icemaker and refrigeration machinery only. Some additional allowance must be made for conveyors, crushers and other equipment.

Many factory vessels carry icemakers for a number of reasons: 1) it would be impracticable to store on board sufficient ice to meet their needs throughout a long voyage; 2) a permanent shore plant would be uneconomic because of the seasonal nature of the fishery; 3) difficulty and delay in obtaining a regular supply from a port ice plant. Although there are a number of valid reasons for considering manufacture of ice at sea the following points should be borne in mind.

It is rarely possible to match production to demand; therefore some ice storage is still required, and the amount of valuable ship space occupied by the ice plant and the store should be carefully worked out. There is sometimes insufficient spare power available on board for making ice, and space may have to be found for an additional generator; 30–35 kW would be required for an ice plant producing 6 tonnes of ice in 24 hours, a production rate that would be reasonable for many boats making weekly trips. The cost of making ice at sea can be higher than the price of ice ashore. Seawater ice is somewhat less suitable than freshwater ice for storing fish, and some ice plant manufacturers now offer desalinators to produce fresh water for making ice on board. Although cheap to operate, more space is again required. Finally, water

for ice manufacture cannot be taken from a dock or from inshore areas that might be contaminated.

To cut down on the amount of ice required, refrigerated sea water (RSW) and chilled sea water (CSW) systems have been developed, and are common on large fishing vessels. Both of these methods have the disadvantage of no longer guaranteeing the maintenance of 0°C and introducing the added expense of temperature control and recording (Jul, 1986). The RSW system is also expensive and installation of a compressor of suitable size to chill large catches is often impractical. CSW systems use tanks of ice and water mixes. Insufficient mixing of the ice and water caused by the tendency of the ice to float in the upper part of the tank can cause temperature control problems. Compressed air, the so-called champagne method, can be used to provide mixing of the fish, water and ice.

There is little data available on the relative energy efficiencies of different at sea chilling options. Few studies have investigated how much fuel/ energy is used to power the refrigeration requirements of fishing vessels and how much is used solely for transport. In assessments that include Ozone layer Depletion Potential (ODP) almost all the ODP is attributed to the use of refrigerators, either used to produce the ice used or provide the refrigeration whilst at sea (Table 9.3). While ice production can contribute up to 10% to Acidification Potential (AP), Abiotic Depletion Potential (ADP), Eutrophication Potential (EP) and GWP associated with catching (Ramos et al., 2011).

9.2.1.2 Freezing at sea There appears to be little specific information on the contribution of freezing at sea to the overall carbon footprint of fishing operations, although many fish products are immediately frozen. Pre-cooling has been shown to reduce the heat load and total energy requirement for the freezing process. For example, pre-chilling of Albacore tuna prior to freezing using a refrigerated seawater system (RSW) removed almost one third of the total heat load and improved the quality of the fish (Kolbe et al., 2004). The RSW system operates more energy more efficiently than a low temperature blast freezer (Kolbe 1990).

Table 9.3 Relative contribution (%) of ice production to AP, ADP, EP, GWP, OLP, METP in relation to the catching of Atlantic mackerel (adapted from Ramos et al., 2011)

	Ice production	Refrigerant emission
Acidification Potential, AP (kg SO_2 eq)	2.3–10.2	
Abiotic Depletion Potential, ADP (kg Sb eq)	2.9–13.2	
Eutrophication Potential, EP (kg PO_4^3 eq)	1.9–8.1	
Global Warming Potential, GWP (kg CO_2 eq)	2.5–11.8	4.2–8.9
Ozone Layer Depletion Potential, ODP (kg CFC-11 eq)	0.1–0.5	89.7–95.8
Marine aquatic Eco-Toxicity Potential, METP (t 1.4 DB eq)	0.5–2.1	

9.2.1.3 Thawing Thawing has received much less attention in the literature than either chilling or freezing. Frozen seafood as supplied to the industry ranges in size and shape from complete tuna to individual fish, although the majority of the material is packed in boxes approximately 5 to 15 cm thick weighing between 5 and 25 kg. Thawing is usually regarded as complete when the centre of the block or fish has reached 0°C, the minimum temperature at which the fish can be boned or cut by hand. Lower temperatures (e.g. −5 to −2°C) are acceptable for processed fish that is destined for mechanical chopping, but such fish is 'tempered' rather than thawed. The two processes should not be confused because tempering only constitutes the initial phase of a complete thawing process.

Thawing is often considered as simply the reversal of the freezing process. However, inherent in thawing is a major problem that does not occur in the freezing operation. The majority of the bacteria that cause spoilage or food poisoning are found on the surfaces of fish. During the freezing operation, surface temperatures are reduced rapidly and bacterial multiplication is severely limited, with bacteria becoming completely dormant below −10°C. In the thawing operation these same surface areas are the first to rise in temperature and bacterial multiplication can recommence. On large objects subjected to long uncontrolled thawing cycles, surface spoilage can occur before the centre regions have fully thawed.

Most systems supply heat to the surface and then rely on conduction to transfer that heat into the centre of the seafood. Most conduction systems are air based, some immersion and a few rely on condensing steam under vacuum. Alternative systems use electro magnetic radiation to generate heat within the fish. In selecting a thawing system for industrial use a balance must be struck between thawing time, appearance and bacteriological condition of product, processing problems such as effluent disposal and the capital and operating costs of the respective systems. Of these factors, thawing time is the principal criterion that governs selection of the system. Appearance, bacteriological condition and weight loss are important if the material is to be sold in the thawed condition but are less so if the seafood is for processing.

There is very little published data on the sustainability of thawing processes. Prior to canning frozen tuna is commonly thawed in running water where weight losses can be typically 0.5 to 1.0% and 720 kg of wastewater may be produced for every tonne of tuna thawed (Uttamangkabovorn et al., 2005). Agitating the water with compressed air can reduce water consumption by approximately 40%.

9.2.1.4 Washing, beheading and filleting Seafood processing operations such as washing, beheading and filleting require large volumes of water and similarly produce large volumes of effluent, which can have a high level of organic contamination. Traditionally, the effluent in coastal regions, where the fish processing industry largely remains, has been pumped out to sea at

negligible cost, but this has changed (Watson, 2003). In a previous survey of fish processing operations (Archer and Watson, 1999) defrosting, filleting and cleaning were identified as the main areas of water use. The survey revealed differences of up to 40% in the efficiency of water use in similar processing operations. Common areas of water wastage included: 1) unnecessarily high flow rates; 2) water supplies left on when not in use; 3) inefficient equipment and 4) leaks. It was reported that simple procedures such as: 1) changes in working practices, 2) installing flow regulators and automatic cut-off valves and 3) fixing leaks could significantly reduce the amount of water wasted.

Filleting, enrobing and cleaning were found to be the main areas associated with high strength effluent production. This could be reduced by: 1) Preventing waste soaking in water; 2) preventing waste getting on the floor; 3) shovelling up all the waste that ended up on the floor and 4) using a 'squeegee' instead of a brush.

9.2.1.5 Secondary chilling and chilled storage The supplementation of the chilling and storage of fish, with mechanical refrigeration has produced some unexpected drawbacks (Jul, 1986). Boxed fish in ice stored at room temperature causes constant thawing and subsequently the production of a constant supply of water at 0°C running over the fish. This produces very efficient heat transfer. Placing the same boxes in refrigerated rooms stops the ice thawing, and the ice instead of cooling the fish acts as an insulating layer.

9.2.1.6 Freezing Air is by far the most widely used method of freezing seafood as it is economical, hygienic and relatively non-corrosive to equipment. Systems range from the most basic in which a fan draws air through a refrigerated coil and blows the cooled air around an insulated room, to purpose-built conveyerized blast freezing tunnels or spirals. Contact freezing methods are based on heat transfer by contact between products and metal surfaces, which in turn are cooled by either primary or secondary refrigerants. Contact (plate) freezing offers several advantages over air-cooling, that is, much better heat transfer and significant energy savings. However, the need for regularly shaped products with large flat surfaces is a major hindrance.

Modern plate cooling systems differ little in principle from the first contact freezer patented in 1929 by Clarence Birdseye. Essentially product is pressed between hollow metal plates containing a circulating refrigerant. A hydraulic cylinder is used to bring the freezing plates into pressure contact with the product. These plates can be either horizontal or vertical. An immersion freezer is made up of a tank with a cooled freezing liquid that can be any non-toxic salt, sugar, or alcohol solution in water and a means of conveying the seafood through the tank. Ice slurries are being considered as an alternative to conventional immersion liquids. These systems achieve higher rates of heat transfer than the single-state liquids.

Cryogenic freezing uses refrigerants, such as liquid nitrogen or solid carbon dioxide, directly. In modern cryogenic freezers as well as using the latent heat absorbed by the boiling liquid, the resulting cold gas absorbs sensible heat. Due to very low operating temperatures and high surface heat transfer coefficients between product and medium, freezing rates of cryogenic systems are often substantially higher than other refrigeration systems.

There is little specific data on the energy use during the freezing of seafood products or differences in efficiency between systems. Winther et al. (2009) reported that it required 0.5 MJ of electrical energy to freeze a kilo of salmon fillet compared with over five times that amount (2.8 MJ) for a filleting process.

9.2.1.7 Cooking Many shellfish are cooked in order to separate the meat from the shells and/or extend shelf-life. Replacing batch cookers with continuous cookers may provide time and energy savings to such processes (Barros et al., 2009a). It has also been suggested that the aromas from shellfish cooking juices may be recovered for use as flavourings (Barros et al., 2009a).

9.2.1.8 Canning For some species like tuna and sardines canning is the most common processing method. Others such as salmon, mackerel, herring, clams, oysters, shrimps, octopus, crab and white fish paste products are also suitable for canning. Specific assessments of the canning of tuna (Tan and Culaba, 2009) and mussels (Iribarren et al., 2010) have been published.

The overall carbon footprint of seafood canning operations depends very much on where the boundaries of the assessment are made. Often the consumer stage of a life cycle assessment is not considered or the footprint contributed by the packaging materials. Canned seafoods do not require refrigerated storage or distribution, or even in some cases cooking by the consumer (Hospido et al., 2006), which offers some energy savings in comparison with refrigerated seafoods. However, the carbon investment in can production is substantial. An assessment, by Iribarren et al. (2010); of canned mussel production identified that can production contributed to over 80% of the total life cycle GHG emissions. Similarly Hospido et al. (2006) identified the primary packaging material used in canned tuna here as ‘the least environmentally-friendly aspect of the industrial process’. They proposed two alternatives to improve the environmental impact: 1) increasing the percentage of recycled material in the tinplate used; or 2) replacing the cans with a more sustainable packaging, such as plastic pouches.

The carbon footprint of canning operations is usually based on electricity and heat consumption by the retorting operation. Consumption will depend on the efficiency of the retorts and source of heating. Often the assessment is based on the total heat requirements for the processing factory, that is, thawing and cooking operations are included as well as retorting (Tan and Culaba, 2009). Few assessments appear to have considered the impact of water use and waste.

Process yield can have a significant effect on the carbon footprint of canning operations. As Tan and Culaba (2009) note, for tuna, cannery yields tend to decrease as the average fish size decreases. This effect may thus result in 'an undesirable feedback loop in which carbon emissions are further exacerbated by the decline in the quality of fish stocks' (Tan and Culaba, 2009). Hospido et al. (2006) reported a process yield of 0.66 kg of canned tuna (net weight) per kg of input.

Tan and Culaba (2009) calculated a partial carbon footprint for tuna canning operations of 0.42–0.48 kg CO_2 per kg. This included all operations within the canning operation, and excluded the footprint contributed by the packaging material.

9.2.1.9 Drying Traditional natural air-drying is environmentally friendly in terms of direct energy using the heat of the sun and wind movement to operate the process. However, such a system is weather dependent and the only control is to directly cover the seafood to protect it during drying. The only ways of increasing the rate of drying are to:

- Increase the exposed surface area.
- Decrease the thickness of the seafood.
- Orient the seafood to maximize its exposure to sun and wind.

An 'artificial' drying system using forced, temperature controlled air provides substantially increased controlled drying rates resulting in improved product quality and a more uniform product. The rate of drying is a function of air temperature, air velocity and the relative humidity of the air. Increasing the air temperature or the air velocity requires an increase in energy and power is also required in any dehumidification system.

9.2.1.10 Salting Seafood, no matter how efficiently it is caught/farmed or processed, inherently has a larger carbon footprint than salt per kilo. Therefore in carbon footprint terms, processed salted seafood products, where a part of the fish has been replaced by salt, are likely to have a lower carbon footprint than unprocessed seafoods. In addition, salting reduces the water content and lowers the volume, thus more product can be transported.

9.2.1.11 Smoking The smoking of seafood is an old traditional method of preserving fish. The preservation effect is a combination of reduced water activity (often enhanced by salting) and the antimicrobial and antioxidant properties of the phenolic compounds deposited by the smoke.

9.2.1.12 Transportation/distribution Sea, air and land transportation systems are expected to maintain the temperature of the food within close limits to ensure its optimum safety and high quality shelf life. It is estimated that

there are approximately 1300 specialized refrigerated cargo ships, 80 000 refrigerated railcars, 650 000 refrigerated containers and 1.2 million refrigerated trucks in use worldwide (Heap, 2006). The type of transportation used will substantially affect the energy used. It has been estimated that the same amount of fuel can transport 5 kg of food only 1 km by personal car, 43 km by air, 740 km by truck, 2400 km by rail, and 3800 km by ship (Brodt et al., 2007). Refrigeration accounts for roughly 40% of the total energy requirement during distribution (McKinnon and Campbell, 1998).

Air-freighting is increasingly being used for high value perishable products, such as live lobsters (Sharp, 1988; Stera, 1999). However, seafoods do not necessarily have to fall into this category to make air transportation viable since it has been shown that 'the intrinsic value of an item has little to do with whether or not it can benefit from air shipment, the deciding factor is not price but mark-up and profit' (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2006). Air is the most intensive form of transport with the highest CO_2 emissions per tonne of the commercial transportation systems (AEA Technology, 2005; Department for Environment, Food and Rural Affairs, 2005; Garnett, 2008).

Over a million refrigerated road vehicles are used to distribute refrigerated foods throughout the world (Gac, 2002; Billiard, 2005). Freight transport consumes nearly 25% of all the petroleum worldwide and produces over 10% of carbon emissions from fossil fuels (Estrada-Flores, 2008). The role of the consumer of this food should not be discounted either. It has been estimated that around one in ten car journeys in the UK are for food shopping (Department for Transport, 2007). The rise in supermarket home delivery services where there are requirements for mixed loads of products that may each require different storage temperatures is also introducing a new complexity to local land delivery (Cairns, 1996).

Frozen vs fresh Few studies have compared the difference between the carbon footprint of transporting different fish commodities. While canned seafood does not require the additional energy of a refrigeration system required for chilled and frozen seafood the additional weight of traditionally canned seafood will have an impact on fuel consumptions. Transport of frozen products requires around 11% more fuel than truck transports without cooling or freezing (Ziegler et al., 2003).

However, while frozen or super-cooled seafood requires more energy than chilled, the longer shelf-life of frozen or super-cooled seafood makes it possible to transport it in a much more efficient manner, especially when long distance transportation is involved (Winther et al., 2009). In addition, frozen and super-cooled seafood does not require the use of ice, unlike the majority of bulk chilled unpackaged seafood. The use of ice in the transport of chilled seafood has a threefold impact in terms of 1) the electricity used for ice production, 2) the fact that iced seafood is usually transported in

refrigerated transporters with additional refrigeration, 3) the impact of the amount of ice on the volume of seafood that can be loaded per pallet, truck and container.

The difference is much more pronounced when freezing makes it possible to transport the product by a much more efficient mode of transport, such as replacing Roll-on/Roll-off (Ro-Ro) car ferries with bulk freight, or replacing air-freight of fresh fish by containerized shipping of frozen fish (Winther et al., 2009). Carbon footprint factors of 0.50, 0.105 and 0.025 kg CO_2/kg-10^3 km have been calculated for air, land (road) and maritime freight, respectively (Tan and Culaba, 2009).

A Norwegian carbon footprint assessment of seafood products (Winther et al., 2009) highlighted a distinct difference between the emissions related to air-freighting of fresh salmon from Norway to Tokyo in comparison with the shipping of frozen salmon to Shanghai. Fulton (2010) reported that the global warming potential of fresh cod fillets delivered to the UK by air from Iceland was 2.6 kg CO_2 eq per kg fillet compared with 0.7 kg CO_2 eq per kg fillet for frozen fillets transported by sea. However, it is unlikely that salmon or cod being shipped by air are being transported alone.

9.2.1.13 Storage Following catching/production many seafoods are transported to centralized 'cold stores' (Europe) or 'refrigerated warehouses' (US) prior to distribution to retailers/end-users. Cold stores may be chilled or frozen, and operate at a range of different temperatures depending on the product or customers requirements. When correctly used these facilities are only required to maintain the temperature of the product.

There is limited published data on energy consumption in cold stores (James and James, 2010). The energy consumption of cold stores depends on many factors, including the quality of the building, activities (chilled or frozen storage), room size, stock turnover, temperature of incoming product, external environmental conditions, and so on (Duiven and Binard, 2002).

In recent years, energy conservation requirements have caused an increased interest in the possibility of using more efficient storage temperatures than have been used to date. For many years, researchers, such as Jul (1982); have questioned the wisdom of storage below $-20°C$ and have asked whether there is any real economic advantage in very low temperature preservation. There is a growing realization that storage lives of several foods can be less dependent on temperature than previously thought. Since research has shown that many food products often produce non-linear time-temperature curves there is probably an optimum storage temperature for a particular food product. Improved packing and preservation of products can also increase storage life and may allow higher storage temperatures to be used. The British Frozen Food Federation (2009) looked at the potential to reduce energy usage and CO_2 emissions by raising the temperature control set point of cold stores and also by raising the associated evaporating temperatures. They reported that 'Savings of over 10% will often

be achievable with relatively little capital investment. Even larger savings of over 20% can be achieved in some situations'.

9.2.1.14 Retail In 2002 it was estimated that there were 322 000 supermarkets and 18 000 hypermarkets worldwide and that the refrigeration equipment in these supermarkets used on average 35–50% of the total energy consumed in these supermarkets (United Nations Environment Programme, 2002). In the retail environment the majority of the refrigeration energy is consumed in chilled and frozen retail display cabinets (James et al., 2009). A German study on the fish cold-chain found that retailing consumed over six times the energy of the next most energy intensive operation, spiral freezing (Meurer and Schwarz, 2003).

Laboratory trials at FRPERC have revealed large, up to six-fold, differences in the energy consumption of frozen food display cabinets of similar display areas. In a chilled retail display, which accounts for a larger share of the market, similar large differences, up to five-fold, were measured. A substantial energy saving can therefore be achieved by simply informing and encouraging retailers to replace energy inefficient cabinets by the best currently available. To quote from an article in the UK's *Guardian* newspaper 'What's the biggest and easiest thing that supermarkets could do to cut their energy bills and reduce their carbon footprint? They all know the answer. Put doors on their fridges' (Pearce, 2009).

The performance of an individual display cabinet does not only depend on its design. Its position within a store and the way the products are positioned within the display area significantly influences product temperatures. In non-integral (remote) cabinets (i.e. those without built-in refrigeration systems) the design and performance of the store's central refrigeration system is also critical to effective temperature control.

9.2.1.15 Catering Refrigerated Commercial Service Cabinets (CSCs) are used to store seafoods in commercial catering facilities. There are approximately 500 000 units in use in the UK alone (Market Transformation Programme, 2006). The vast majority of the cabinets sold are integral cabinets (refrigeration system on board the unit). Most of the market is for chilled or frozen upright cabinets with one or two doors or under counter units with up to four doors. The average energy consumption in the UK for chilled cabinets is 2920 kWh per year and for frozen is 5475 kWh per year (Market Transformation Programme, 2006). It is not clear what proportion of this can be attributed to the storage of seafoods.

Although each cabinet type is of similar size and therefore can be directly compared in terms of functionality, there is a large difference in energy consumed by each type of CSC. It has been estimated that simply replacing current CSC cabinets in the UK by the best available, in terms of energy consumption, could save 1000 GWh per year (James et al., 2009).

9.2.1.16 Domestic storage Domestic refrigerated storage is an often unregarded part of the food cold-chain by the food industry. However, from an environmental point of view this sector is important. There are approximately 1 billion domestic refrigerators worldwide (International Institute of Refrigeration (IIR, 2002)). At present, most of these are in industrialized countries. However (as noted by Billiard, 2005), production in developing countries is rising steadily (30% of total production in 2000). When the environmental impact of these refrigerators is considered using a LCCP (Life Cycle Climate Performance) approach, the emissions of refrigerant in a domestic HFC-134a refrigerator represent only 1–2% of the total contribution to global warming while emissions due to energy consumption represent 98–99% (Billiard, 2005). Therefore, energy consumption is the most significant issue with regards to global warming.

A ten-year-old refrigerator uses 2.7 times as much energy per litre usable volume as a new A-class one (Carlsson-Kanyama and Faist, 2000). This has a clear effect on energy consumption. However, considerable energy is needed to produce a new domestic refrigerator so there will be an increase in emissions in the short term if there were a wholesale programme of replacement.

Some researchers (Estrada-Flores, 2008) have pointed out that the need for more energy-efficient domestic appliances will need to be balanced with the fact that food products will become more expensive and therefore, more valuable. Thus, consumers will demand that domestic refrigerators, freezers and other storage solutions that maximize product shelf-life. Chilled seafood has a particularly short shelf-life and is often not stored at present under ideal conditions in the home. Ideally seafood should be stored at a temperature close to that of melting ice (0°C), whereas surveys show that the average temperature of a refrigerator is 6 to 7°C throughout the world (James et al., 2008). While lowering operating temperatures may increase energy use this may be offset by a reduction in waste. However it is an area that does not appear to have been studied in any great detail as yet.

9.2.2 Overall

The catching and processing of fish generates a significant amount of waste. For example, it has been estimated that 57% of the total UK fish and shellfish resource is classed as waste (Archer, 2001). The majority of waste (Archer, 2001) is produced in the on-shore processing sector (35% of the resource) whereas discards and processing waste at sea produce smaller quantities (17% and 5% respectively of the resource cycle of the studied product), followed by transports. In a Life Cycle Assessment of Swedish frozen cod production (Ziegler et al., 2003), product loss (e.g. losses in the industry or in the household) was identified as the most important factor after landing on the overall environmental impact of the product.

Fish waste is rich in potentially valuable oils, minerals, enzymes, pigments and flavours and so on, that have many alternative uses in food, pharmaceutical, agricultural, aquacultural and industrial applications (Archer, 2001). The most common use of fish waste is for fishmeal and oil production. Other uses are in silage production, fertilizer, composting, fish protein hydrolysate, anti-freeze proteins and fish protein concentrate (Archer, 2001; Blanco et al., 2007). Non-nutritional uses include aggregates in construction materials, chitin and chitosan, carotenoid pigments, enzyme extraction, leather, glue, pharmaceuticals, cosmetics, fine chemicals, calcium carbonate, collagen, gelatin and pearl essence (Archer, 2001; Blanco et al., 2007; Barros et al., 2009b).

9.3 Resource management strategies

9.3.1 Water and effluent

Duangpaseuth et al. (2007) produced the following simple tips for water saving during fish processing.

- Install fixtures that restrict or control the flow of water for manual cleaning processes. Reuse relatively clean wastewaters for other applications.
- Use compressed air instead of water where appropriate.
- Install meters on high use equipment to monitor consumption.
- Use closed circuit cooling systems.
- Pre-soak floors and equipment to loosen dirt before the final clean.
- Report and fix leaks promptly.

In addition they produced the following tips for reducing effluent loads:

- Sweep up solid materials for use as a by-product, instead of washing them down the drain.
- Clean dressed fish with vacuum hoses and collect the blood and offal in an offal hopper rather than the effluent system.
- Fit drains with screens and/or traps to prevent solid materials from entering the effluent system.
- Use dry cleaning techniques where possible, by scraping equipment before cleaning, pre-cleaning with air guns and cleaning floor spills with squeegees.

9.3.2 Post-harvest losses

About one third of the world total catch of fish goes to non-food uses, mainly as fishmeal and fish oil for animal/fish feeds (Hall, 2011). While those fish discarded at sea (by-catch) or converted to fish meal may be considered post-harvest losses, the term is more usually associated with post-landing losses.

Fish are highly perishable and inadequate processing and/or poor infrastructure can result in significant waste.

9.3.3 Impact of climate change

Any noticeable increase in ambient temperature resulting from climatic change will have a substantial effect on the current and developing fish supply, processing and cold-chain. Marshall (2012) states 'Many tropical species are already living right at, or even slightly above, their optimum temperature'. A rise in temperature will have a direct impact on the availability of fish and is likely to increase the risk of food poisoning and food spoilage unless the cold-chain is extended and improved. Any substantial rise in average ambient temperatures will also impose higher heat loads on all systems in the cold-chain.

Currently food is frozen to and generally maintained at a temperature below −18°C throughout storage, transport, retailing and domestic storage. In the case of frozen food, if the food industries' response to a 2 to 4°C rise in ambient temperatures were to allow a similar rise in the food temperature, then food poisoning and spoilage would not increase. However, if this were universally adopted then the high quality storage life of many temperature sensitive seafood products, such as oily fish and tuna, would potentially deteriorate.

9.4 Future opportunities

9.4.1 Improving fuel use

The fuel used by fishing boats is a major component of the total energy used in the production of seafood. Fulton (2010) outlined many ways for improving the fuel efficiency of fishing boats. These included maintaining existing and retrofitting with new engines; optimizing propeller size and efficiency can also make significant improvements: reducing the speed at which the boat is operated is also a factor, as is the skill of the skipper; hull shape is another obvious factor in fuel efficiency as is the condition of the hull and hull size. The choice of fishing gear has an unclear impact on fuel efficiency – one gear is not clearly likely to be less fuel intensive than another. However, certain gear types may be more efficient under certain circumstances and the size, type and material resistance of gear are all possible considerations when examining fuel efficiency. Both Lee et al. (2010) and Ivanovic and Nielsen (2010), have examined designs for trawl nets that reduce drag while maintaining catch performance.

9.4.2 Cold-chain management

Refrigeration has been identified as an area where dramatic emission cuts could be made relatively easily, by using and maintaining energy-efficient equipment correctly (International Institute of Refrigeration (IIR), 2003).

It is clear that maintenance of seafood refrigeration systems will reduce energy consumption (James et al., 2009). Repairing door seals and door curtains, ensuring that doors can be closed and cleaning condensers produce significant reductions in energy consumption. In large cold storage sites it has been shown that energy can be substantially reduced if door protection is improved, pedestrian doors fitted, liquid pressure amplification pumps fitted, defrosts optimized, suction liquid heat exchangers fitted and other minor issues corrected. Also, it is well known that the insulation efficiency of insulated panels can reduce by 5 to 12% per year (Estrada-Flores, 2009).

Better design of facilities can also reduce energy consumption. Among the suggested improvements (Duiven and Binard, 2002) are: thicker floor, wall and roof insulation; use of in-feed and out-feed conveyors with lock gates instead of doors; selection of the right compressor and refrigerant; appropriate selection of components of the refrigeration process; application of speed control for compressors to achieve full-load during refrigeration, as well as speed control of fans; electronic expansion valves; adequate pipe dimensions and insulation; advanced lighting methods; defrosting using hot gas; computer control systems, monitoring and data processing.

9.4.3 Shortening the supply chain

Traditionally fish have passed through a supply chain that has included fish markets and wholesalers. Increasingly processors/retailers are obtaining the product directly. This not only lowers costs for processors/retailers and improves freshness, but it also may reduce the environmental impact (Vázquez-Rowe et al., 2011) by reducing transport distances, double handling and secondary packing and so on.

9.4.4 Energy balance

The purpose of a seafood processing factory is to take a supply of raw materials and packaging and transform them in the most cost efficient manner into a finished packaged product. In a recent example investigated by FRPERC the input of the factory was 350 tonnes of raw fish at −20°C and 125 tonnes at 0°C, per week. The output was 400 tonnes of finished product at 3°C and 75 tonnes of waste material at 12°C. During processing the heat energy in the food and waste had therefore increased from 32 500 million kJ to 121 525 million kJ. However, the factory used the majority of its electrical energy consumption to maintain refrigeration plants. This appears non-sensible if the whole process required the seafood to gain heat.

A detailed investigation was therefore carried out to determine what the refrigeration plants were actually doing and to see if there were far more

energy efficient methods of processing the fish. Initial studies revealed that there was a substantial base energy load in the factory. For example the factory used over 500 kWh of energy per hour on nights in December when the average ambient temperature was below 0°C, there was no production in the factory and all the doors were closed. Further investigations revealed that there was no relationship between throughput and energy usage.

In addition to large refrigerated storage areas for raw material and finished product all the processing areas were also refrigerated. Heat generated by evaporator fans, defrosts, lighting, people and especially infiltration through the structure resulted in large heat loads in these areas. However, in a well-controlled process the time required to process the fish was only a few minutes and the heat pick up very small. As in many food factories the environment was refrigerated rather than the food itself.

Refrigeration is important in both maintaining the safety and quality of many foods and enabling food to be supplied to an increasingly urbanized world. In reality, less than 10% of such perishable foodstuffs are in fact currently refrigerated (Coulomb, 2008). It is estimated that post-harvest losses currently account for 30% of total production (Coulomb, 2008). The production of food involves a significant carbon investment that is squandered if the food is then not utilized. Thus there is a balance to be achieved. The International Institute of Refrigeration (2009) estimate that, in theory, if developing countries could acquire the same level of refrigerated equipment as that in industrialized countries, over 200 million tonnes of perishable foods would be preserved, this being roughly 14% of the current consumption in these countries.

9.5 Conclusions

The seafood industry is a major user of energy and water and it produces a significant amount of effluent throughout its production processes from initial catch to consumer consumption.

Current data suggests that the fuel used by fishing boats is the single most important element contributing to excessive energy usage. Improvements in fuel efficiency and catching methods would therefore substantially improve the sustainability of seafood production.

Refrigeration is also a major user of energy in fish production. The little data that is available suggests that currently the cold-chain accounts for approximately 1% of CO_2 production in the world, however, what proportion of this relates to seafood is not known. However, this is likely to increase if global temperatures increase significantly. Energy efficiency is increasingly of concern to the food industry mainly due to substantially increased energy costs and pressure from retailers to operate zero carbon production systems. Reducing energy in the cold chain has a big part to play since worldwide it is estimated that 40% of all food requires refrigeration and 15% of the

electricity consumed worldwide is used for refrigeration. Simple solutions such as the maintenance of food refrigeration systems will reduce energy consumption. Repairing door seals and door curtains, ensuring that doors can be closed and cleaning condensers produce significant reductions in energy consumption. In large cold storage sites it has been shown that energy can be substantially reduced if door protection is improved, pedestrian doors fitted, liquid pressure amplification pumps fitted, defrosts optimized, suction liquid heat exchangers fitted and other minor issues corrected.

Many simple changes to operational practice and the introduction of simple technologies would appear to make a substantial input to reducing both water consumption and the effluent produced in seafood production. These are as simple as turning off water taps when not in use.

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10 Sustainable Processing of Fresh-Cut Fruit and Vegetables

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10.1 Introduction

Nowadays, the beneficial effect of fruit and vegetable consumption on human health is well known, in part due to the scientific and technological advances during the last decades. Several epidemiological studies have demonstrated the association between fruit and vegetable consumption, with powerful antioxidant effects, and the prevention of some cancers and cardiovascular diseases. In this way their consumption has been promoted by researchers, nutritionists, and even at a governmental level, and currently consumers demand fresh, healthy and easy to prepare or ready-to-eat plant products. In particular, minimally processed or fresh-cut fruit and vegetables are commodities that connect well within the new consumer trends since they are practically free from additives, packaged under modified atmosphere packaging (MAP), distributed at chilling temperatures and are ready to eat. The main advantage of fresh-cut plant foods is that they have almost the same properties as the whole intact product, but require a much reduced elaboration time and with a uniform and consistent quality (Artés and Allende, 2005).

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This chapter summarizes the principles and development of emerging sustainable techniques for the fresh-cut plant products processing industry to improve its overall quality and safety in order to meet the expected market's demand.

10.2 Unit operations for fresh-cut fruit and vegetable processing

In general fresh cut fruit and vegetables undergo minimally processing which includes washing, cleaning, peeling and cutting. Peeling and cutting induces metabolic reactions within the living tissues, causing increased respiration rate (RR) and the potential for compromising texture changes, accelerated ripening and/or senescence, off flavours, discolouration and other undesirable events (Toivonen and Brummel, 2008). Processing can also result in an increased ethylene production which promotes ripening and senescence (Orsat et al., 2001). Moreover, removing the protective peel of fresh produce leaves a cut surface that is covered with water caused by cell wall cell disruption, which makes it convenient for microbial development (Huxsoll and Bolin, 1989).

Therefore, deterioration of fresh-cut fruit and vegetables is mainly due to further physiological ageing, biochemical changes and microbial spoilage, all of which can render the product unmarketable (Nguyen-The and Carlin, 1994; Ahvenainen, 1996). Among others, the adverse changes affecting fresh-cut horticultural produce are off-odours, off-flavours, browning, discolouration, softening (loss of crispness or juiciness) and water loss (Artés et al., 2007).

Browning of fresh fruit and vegetables is a frequent problem during postharvest handling, processing and storage, being one of the major causes of quality loss and spoilage which reduces quality and limits shelf life and marketability of fresh-cut products (Vamós-Vigyázó, 1981; Huxsoll and Bolin, 1989; Sapers, 1993; Pirovani et al., 1997; Hodges and Toivonen, 2008). This phenomenon can be due to enzymatic and non-enzymatic reactions. Enzymatic or oxidative browning requires different components: enzymes such as polyphenol oxidase (PPO), and peroxidase (POD), a substrate, usually phenolics compounds, and co-substrates such as O_2 and H_2O_2. Browning takes place at the cut surface of fruit and vegetables because of decompartmentation happening when cells are broken, allowing substrates and oxidizers to combine. The brown colour development is related primarily to oxidation of phenolics compounds including monophenols, triphenols, and *o*- and *p*-diphenols to *o*-quinones, a reaction catalyzed by PPO and POD (Artés et al., 1998). These phenolics compounds are produced from the amino acid L-phenylalanine to *trans*-cinnamic acid catalyzed by phenylalanine ammonia liase enzyme (PAL) to *p*-coumarate. Subsequent reactions produce several new compounds, to form chlorogenic and isochlorogenic acids and, with tartaric acid, to form caffeoltartaric and dicaffeoltartaric acids (Castañer

et al., 1999; Tomás-Barberán et al., 1997). The oxidation products of these reactions, *o*-quinones, polymerize with each other and react with NH_2 or SH groups from aminoacids and proteins, and with reducing sugars, giving complexes of high molecular weight polymers of unknown structure which leads to the formation of dark brown or black pigments (Vámos-Vigyázó, 1981). It was reported that wounding also induces synthesis of some enzymes involved in browning reactions or substrate biosynthesis (Brecht, 1995; Cabezas-Serrano et al., 2009; Amodio et al., 2011). In cut, bruised or senescent plant products this oxidative reaction occurs rapidly, with the fresh-cut commodities being highly susceptible to oxidative browning reactions. Given the deleterious effects of PPO activity upon the sensory and nutritional quality of fresh-cut produce, it is not surprising that considerable research has been devoted to inhibit its activity (Cliffe-Byrnes and O'Beirne, 2008).

Several factors affect the shelf life and microbial quality of fresh-cut plant commodities like agricultural practices at the farm, hygienic practices during harvesting and handling, quality of washing water, processing technologies, packaging methods and materials, and transportation, processing, storage and retail sale temperatures (Shewfelt, 1986; Brackett, 1987; Bolin and Huxsoll, 1989; Ahvenainen, 2000; Artés, 2004; Nicola et al., 2009). The distribution chain of food products is composed of many different steps in storage and transportation until consumption, and traceability is today a key concept (Allende et al., 2004).

Protected cultivation of raw material for the fresh-cut industry, when they are used, show several advantages compared to the open field system. Among others, a protection from adverse weather conditions, a reduction in evapotranspiration rate, an increase in photosynthesis rate, an advance in the harvest date, and higher internal air temperature. All these factors commonly improve plant health and raw material quality, yield and safety (Nicola et al., 2009). In addition to this, to assure the safety and quality of all incoming raw materials, implementation of integrated pest management and a quality management standard such as ISO9000:2000 have been recommended as a starting point for an agreement between the supplier and the fresh handling produce manufacturer which should include a hazard analysis of critical control points (HACCP) to identify what could go wrong (Tomás-Callejas et al., 2011a). Proper storage conditions of fruit and vegetables before processing are crucial for the production of commodities of good quality (Wiley, 1994). Finally, it is necessary to evaluate rapidly and non-destructively the quality of plant raw materials when received in the factory for safety aspects like pesticide residues, microbial load, toxic metals, naturally present undesirable compounds, and plant growth regulators (Yildiz, 1994).

The traditional fresh-cut processing usually consists of a sequence of unit operations (trimming, peeling, cutting, washing, disinfection, dewatering, centrifugation, drying and packaging). Generally, the extension of the shelf life depends on a combination of a proper temperature management

throughout the entire cold chain, dipping in anti-browning solutions, optimal packaging conditions, usually under Modified Atmosphere Packaging (MAP), and good manufacturing and handling practices in well designed factories (IFPA, 2004; Artés and Allende, 2005; Artés et al., 2009). Additionally, some authors have proposed the use of edible coatings in combination with anti-browning agents to improve the colour preservation of fresh-cut commodities (Rojas-Argudo et al., 2009).

The main objective of the processors throughout all processing operations involved in the production of fresh-cut produce is food safety, quality optimization and reduction of losses (Shewfelt, 1999). For that reason a relationship between Industry-Academia-Government with common research concerning would be ideal (Osterholm et al., 2009). Frequent practices consist of the protection of the produce from damage caused by poor handling or machinery functioning, foreign body contamination and/or pest infestation (Day, 2000). In addition, human contamination during handling, washing, drying and packaging may occur from unhygienic personnel (Hurst, 1995; Francis et al., 1999). Therefore, although worker sanitation is an aspect that is too often neglected when processing fresh plant products, good manufacturing practices must be accomplished and all food handlers must be supervised and trained in food hygiene matters related with their work activities (Brackett, 1992).

The general sequences of unit operations in a typical industrial factory of fresh-cut horticultural produce and the maximum recommended temperatures for each processing step are shown in Figure 10.1. The first step in a fresh-cut factory is generally sanitation of whole products to eliminate unwanted dirt, pesticide residues, plant debris, soil, insects and foreign matter, and retardation of the enzymatic discolouration reactions (Soliva-Fortuny and Martín-Belloso, 2003). For surface sanitation and sterilization of plant products to prevent microbial inoculation it is common practice to use sodium or calcium hypochlorite although after pathogens have infected their host, chlorination is not very effective (Hong and Gross, 1998).

The crucial stage in reducing the overall contamination on fresh-cut fruit and vegetables is elimination of the inedible parts (peduncles, tops, stalks, calyx, core, outer or damaged leaves, etc.) before additional processing. All conditioning operations should be conducted under temperature controlled (5 to 10 °C) areas. Peeling and cutting operations constitute a critical hygienic point in the processing line, and the equipment used in this operation needs to be cleaned, disinfected and sharpened at regular intervals every working day to avoid build-up of organic residues. The physical damage, physiological stress, and increase of microbial growth caused in this step are well documented (Barry-Ryan and O'Beirne, 1999; Ahvenainen, 2000; Soliva-Fortuny and Martín-Belloso, 2003; Artés et al., 2007). These changes are mainly caused by the increase of RR and C_2H_4 production due to mechanical injuries which results in the release of intracellular oxidizing enzymes and substrates and leads to various biochemical deteriorations such as browning, and increased

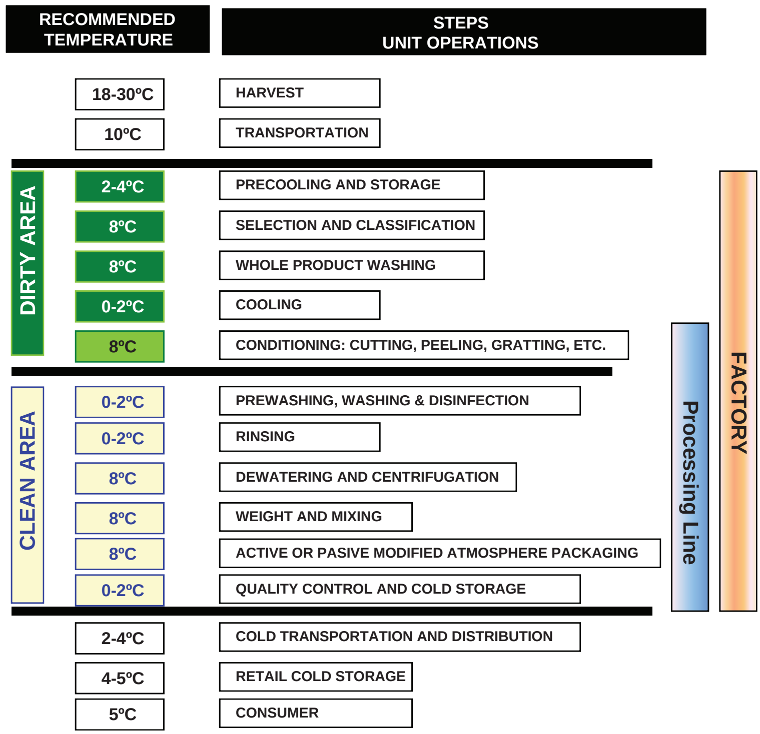

Figure 10.1 Usual steps and unit operations for processing and commercialization of fresh-cut plant produce.

availability of cell juice and nutrients (Varoquaux and Wiley, 1994). The fluid exudation of bruised and cut surface tissues can lead to a high difficulty for keeping quality and shelf life of some fresh-cut produce. In the same way, the cut type had a great influence on the shelf life of fresh-cut lemons, mostly when conditioning temperatures are higher than the recommended 5 °C (Artés-Hernández et al., 2007).

Therefore, cutting appears to have a dramatic effect on nutritional value, overall quality and shelf life of fresh-cut fruit and vegetables (Watada et al., 1990; Barry-Ryan and O'Beirne, 1999; Ahvenainen, 2000; Artés et al., 2009), although fresh-cut fruits often visually spoil before any significant nutrient loss occurs (Gil et al., 2006). Many different peeling machines are commercially available but peeling is normally accomplished manually, mechanically, chemically or in high-pressure steam peelers (Wiley, 1994). At the same time, several methods are able for cutting, grating, chopping, shredding or slicing fresh plant produce into pieces of several shapes and sizes.

Washing after peeling and/or cutting is a critical step of the elaboration process. Sanitization has been defined as the art of treat cleaning the produce

by a process that is effective in destroying or substantially reducing the numbers of microorganisms of public health concern, as well as other undesirable microorganisms, without adversely affecting the quality of the product or its safety for the consumer (FDA, 1998a). Washing procedures applied to fresh produce have the potential to reduce contamination from the surface of the product. However, washing water may also cause cross-contamination within a batch and among sequentially washed batches. Due to economic and environmental factors, water reconditioning and recycling has been a long employed practice for the industry recommended by governmental institutions (USDA, 1999).

Washing and disinfection are the only steps in the production chain where a reduction in the microbial load can be obtained, thus minimizing populations of potential pathogens (Nguyen-The and Carlin, 1994; Beuchat, 1998; Day, 2001; Gómez-López et al., 2008; Artés et al., 2009). However, published efficacy data indicate that these conventional, time-consuming methods are not capable of reducing microbial population on produce by more than 90 to 99% and that is insufficient to assure microbial safety (Sapers, 2001). Sanitizers are primarily used to maintain bacteriological quality of the water rather than the produce (Brackett, 1999).

Washing can be achieved by very simply spraying with potable water, although it generally involves the complete immersion of the produce in cold (1–5 °C) sanitized water in a bath (Artés et al., 2009). Systems that ensure complete immersion of the individual cut product in the wash water by injecting compressed air will improve its performance, because the turbulence generated by the aeration allows the elimination of almost all traces of soil and foreign matter without damage to the product (Yildiz, 1994).

A great number of antimicrobial washing solutions specifically for whole vegetable products have been reported. The most widely used is NaOCl solution containing 50–150 ppm of available chlorine, acidified with about 150 to 200 ppm of citric acid to adjust pH values to about 6.5–7.0 for optimizing the chlorine efficacy (Brackett, 1992; Kim et al., 1999a; Artés et al., 2009). When chlorine gas (Cl_2) or hypochlorite salt (e.g., NaOCl or $Ca(OCl)_2$) is added to water, they will generate Cl_2, hypochlorous acid (HOCl), which is the active form, or hypochlorite ions (OCl^-) in various proportions, depending on the pH of the solution. However, the antimicrobial activity of hypochlorite solutions is related to the concentrations of undissociated OCl^- and HOCl (Adams et al., 1989). There is no unified criterion about the recommended free chlorine concentration and contact time for the disinfection washing. Therefore, it has been recommended 50–200 ppm total chlorine and contact times of 1–2 min for this purpose (FDA, 1998b) and the International Fresh-Cut Produce Association (IFPA, 2001) Model HACCP Plan for shredded lettuce, suggests a maximum of 150 ppm total chlorine at pH 6.0–7.0 and the maintenance of 2–7 ppm free residual chlorine after contact (Delaquis et al., 2004; Soriano et al., 2005). It is remarkable that chlorinated washing produce can

effectively remove sand, soil and other debris from fresh fruits and vegetables but should not be relied upon to completely remove organisms (Bracket, 1992). Several reviews have reported a mean of 2 to 3 log unit reduction of food-borne pathogens by washing produce with chlorinated water up to 2–3 min. (Soliva-Fortuny and Martín-Belloso, 2003; Rico et al., 2007; Artés et al., 2009; Tomás-Callejas et al., 2012).

After disinfection the product must be rinsed. This stage is commonly done by using cold (1 to 2 °C) water showers or dips. The final chlorine residue in the product must be lower than 5 ppm, although the legal limit may vary from country to country. Contact times between the produce and the wash water are usually less than 5 minutes throughout all the washing stages (Artés and Allende, 2005).

The next critical processing unit operation is to remove the excess of water in the surface of the produce. Dewatering wet surfaces must be carried out carefully to avoid unnecessary damage to the plant tissues, reducing the product moisture content and removal of cell leakage that can support microbial growth (Soliva-Fortuny and Martín Belloso, 2003). Dewatering systems include draining systems, gentle removal with cheesecloth, centrifugal spin dryers, vibrating racks, rotating conveyors, hydro-sieves, forced air and spinless drying tunnels (Gorny et al., 2002). The most used technique for leafy vegetables is centrifugation, although the high centrifugal force not only removes water, but also cracks and crushes the tissues (Ahvenainen, 2000). Forced cold air injected over a perforated conveyor belt, which transports the product has been recently applied as an industrial alternative to the conventional dewatering systems. However, their main inconvenience is the low efficiency for high volumes of product where hot air is used as a first step to accelerate drying and then cold air is used to end the process. Another technique recently developed is the use of infrared light to remove the water excess on commodities surface. However, it still has two main problems for their industrial application, the high financial investment and the large area needed in the processing plant to install the device (Artés-Hernández and Artés, 2005).

Then products are weighted and mixed (if necessary) before packaging. Fresh-cut products are usually kept under MAP to achieve the needed commercial shelf life. The aim of the MAP technique is to create an optimum atmosphere around the packaged produce, which retards their metabolism and deterioration in such a way that the tolerated minimal O_2 or maximum CO_2 concentrations are not exceeded, in order to avoid a shift towards fermentation or other metabolic or biochemical disorders (Toivonen and Brummell, 2008). The desired gas composition is generated and stabilized by the interaction between the RR of the plant commodity and the permeability of polymer (passive modification) or is firstly partially or totally prepared and then injected into the package (active modification) in order to accelerate the stabilization of the required atmosphere (Artés et al., 2012).

The design and selection of the appropriate polymeric film used for sealing bags, trays or bowls is crucial. In this way, when temperature could be abusive during transport, distribution and/or retail sale, the use of microperforations in polymeric films is recommended (González-Buesa et al., 2009; Rojas-Grau et al., 2009; Artés et al., 2012).

Most of the existing models for designing MAP are based on the analysis of equilibrium atmospheres within packages. This is because a proper steady atmosphere for keeping overall quality of whole and fresh-cut produce is generated by a balance among RR, product weight, film area and permeability. Modelling, including software, can be developed and used as a tool to speedily analyse the adequacy of various packaging systems to generate a proper equilibrium atmosphere for each packaged product. It has also been found to fairly accurately simulate the evolution of the gas composition at any temperature, simulating real-life distribution chain and thus testing the ability of the package to withstand abuse (Mahajan et al., 2007). When a new package design is proposed, its performance should be predicted rather than requiring costly experimental evaluation of prototypes.

In the market there are several polymers for packaging that allow a wide range of gas diffusion, although only a few have suitable characteristics to generate a proper MA in fresh-cut fruit and vegetables (Artés et al., 2006). In the conventional non-perforated films, the film selectivity (PCO_2/PO_2) must be between 2 and 8 (Artés et al., 2006). However, perforations allow for a much higher exchange rate of gases than conventional films. Thus the microperforated and microporous films have a permeability that depends on the number and diameter of the holes/pores, and the selectivity is considered to be around 1, which means that the sum of the levels of O_2 and CO_2 is around 21 kPa. For that reason, they are classified as non-selective and their permeability ranges from 6000 to 120 000 $mL\,m^{-2}\,day^{-1}\,atm^{-1}$ at 25 °C (Ghosh and Anantheswaran, 2001).

Among the available types of polymers used for packaging fresh-cut fruit and vegetables, the most commonly used are: polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), ethylene and vinyl acetate copolymer (EVA), and polystyrene (PS). They are used as simple or complex films (using suitable adhesives or manufactured by coextrusion), and have permeability ranges that are very broad and very specific. The polyolefins group (including PE and PP among others) is widely used in microperforated and conventional films, being characterized by their low water vapour and high gas permeability, and good thermal heat sealing (Artés et al., 2006).

Nowadays there is an emerging research in ‘active’ and ‘intelligent’ food packaging techniques based on a deliberate interaction of the packaging with the food and/or its direct environment. The purpose of active packaging is the extension of the shelf-life of the food and the maintenance of its quality, while the purpose of intelligent packaging is to give an indication on, and to monitor, the freshness (Dainelli et al., 2008). Intelligent packaging systems, usually

contain attached labels on packaging material, and offer enhanced possibilities to monitor product quality, trace critical points, and give more detailed information throughout the supply chain (Han et al., 2005). Active packages include components intended to release or absorb substances into or from the food and/or from the surrounding environment. Active MAP for fresh-cut produce is more focused on gas-flushing, gas-scavenging or emitting systems added to emit (e.g., N_2, CO_2, ethanol) and/or to remove (e.g., O_2, CO_2) gases during commercialization. Alternatively, the active principle can be incorporated in any of the materials that constitute the package, such as on the internal surface of the package walls or in the matrix of the polymeric structure. This technique is preferred nowadays because the consumer does not encounter a foreign object within the package which may be considered unsafe (Gavara et al., 2009).

It could be interesting to introduce innovative techniques already applied in other sectors like the use of the 'clean room technology'. This technique consists of installing a filtered air system in the packaging area where the environment has a controlled level of contamination that is specified by the number of particles per cubic meter at a specified particle size (Havet and Hennequin, 1999; Artés-Hernández and Artés, 2005; Silveira et al., 2010).

Once the product is sealed, bags pass by simple bag conveyors through weight control and metal detectors. From this point some bags are randomly taken for quality control and the rest are immediately put into boxes for consignment and picking of loads. Finally, the product lots are directly chilled and transported onto temperature-controlled trucks to different distribution places like local markets, distribution centres, logistic platforms, and then transported to supermarkets and retail display cabinets (Artés, 2000; Artés-Hernández and Artés, 2005).

Knowledge about the time-temperature conditions in the cold-chain of fresh-cut fruit and vegetables is needed to determine the influence on the quality loss and the shelf life of these products. Although throughout the distribution chain, the commodities must be kept at 1–5 °C to ensure quality and shelf life, it is almost impossible to guarantee that this temperature will be maintained during transportation, distribution and retail display (Orsat et al., 2001). In fact, it was already demonstrated that these products are often subjected to temperature abuse of about 12 °C in the display cabinets for a long time while in the supermarkets (Willocx, 1995).

10.3 Eco-friendly alternative sanitations techniques to preserve quality and safety

Enteric diseases linked to consumption of fresh and fresh-cut produce have increased in the last several decades (Scallan et al., 2011). *Escherichia coli* O157:H7 (CDPH, 2005; CDC, 2006) and *Salmonella spp*. (Hanning et al.,

2009; Raybaudi-Massilia et al., 2009) have been associated with multiple outbreaks linked to the consumption of fresh and fresh-cut vegetables in Europe and the US. In May 2011, a very important outbreak in Germany and France related to infected seeds for sprouting with Shiga toxin-producing *E. coli* (STEC) O154:H4 was reported. As of June 2011, the STEC O104:H4 outbreak resulted in 3774 cases of infections in the EU. Of these, 750 were complicated by hemolytic uremic syndrome (HUS) and 44 infected people died (Scheutz et al., 2011).

Diverse opportunities for primary contamination and cross-contamination during preharvest phases and postharvest handling are recognized. Among these fecal contamination by animals or transmission by insects, use of untreated manure, application of contaminated irrigation or foliar contact water, flood water carrying human waste and direct human hand contact are included (Suslow et al., 2003; Brandl, 2006). As fresh-cut plant commodities are typically consumed raw, prevention and sanitation become the most important tools for keeping their microbial quality and safety (Artés et al., 2009).

The specific operations involved in preparation of fresh-cut vegetables can facilitate attachment and stimulate microbial growth, which includes diverse complexes of spoilage microbiota and bacterial pathogens harmful to human health (Sapers et al., 2006). Therefore, fresh-cut produce must be managed in primary production phases and elaborated for marketing following strict control procedures for reducing overall quality loss and assuring its safety to consumers (Artés et al., 2009).

Efficacy of the method used to reduce microbial populations usually depends upon the type of treatment, type and physiology of the target microorganisms, characteristics of produce surfaces (cracks, crevices, hydrophobic tendency and texture), attachment of cells to produce surfaces, formation of resistant biofilms and internalization of microorganisms, exposure time and concentration of sanitizer, pH and temperature. It should be noted that the concentration/level of sanitizers or other intervention methods may be limited by unacceptable sensory impact on the produce (Issa-Zacharia et al., 2010). Additionally, the remaining microbial load could grow rapidly, reaching similar values to those of unwashed products. Hence, maintenance of this reduction during storage is as important as initial microbial reductions after washing (Ragaert et al., 2007).

Chlorination of water is one of the primary elements of a properly managed postharvest sanitation programme. This operation is considered as the most important to disinfect water and minimize the transmission of pathogens from infested plant produce, water or debris, to non-infested surfaces such as those mechanically injured during harvesting, transportation or processing, wounds, or the natural plant surface openings (Artés et al., 2009). NaClO is a potent disinfectant with strong oxidizing properties. However, disadvantages related to its use include the formation of potentially hazardous disinfection-by-products, its strong pH dependence, and the potential for gas emission that

may affect worker health (Ölmez and Kretzschmar, 2009a). NaClO may partially oxidize food constituents to form secondary products such as chloroform ($CHCl_3$), haloacetic acids or other trihalomethanes (THM) that have known or suspected carcinogenic or mutagenic potential effect, with proven toxicity to liver and kidney tissues (Nieuwenhuijsen et al., 2000; Hrudey, 2009). Due to the above mentioned concerns, efforts to identify and evaluate alternative sanitizing agents to chlorine has become of increasing concern and priority for various industry sectors. Following the principle of 'hurdle technology', a combination of various preservation techniques at lower individual intensities can have additive or even synergistic antimicrobial effects, while their impact on sensory and nutritive properties of the food is minimized (Leistner and Gould, 2002). In that sense, some combined technologies are also subsequently revised.

10.3.1 Alternative washing solutions

10.3.1.1 Peroxyacetic acid Peroxyacetic acid (PA) is a strong oxidant that has been demonstrated to be effective against spoilage and pathogens microorganisms (Rodgers et al., 2004). PA is a combination of peracetic acid (CH_3CO_3H) and H_2O_2, and typically commercialized as a liquid. PA is an interesting alternative to NaClO since its break-down products, acetic acid, O_2, CO_2, and water makes its use completely sustainable and eco-friendly. The US FDA has set a minimum of 85 ppm PA for cleaning hard surfaces where food is handled (FDA, 1997). Regarding the mechanism of action of PA, it has been suggested to act primarily on lipoproteins in the cell membrane, and it may be possible that it is equally effective against outer membranes lipoproteins, facilitating its action against Gram-negative cells (Leaper, 1984).

PA tolerates several adverse factors like a wide range of temperature application, pH changes (from 1 to 8), water solutions with high carbonate concentration and soil contamination. By these positive sides, its current main area of application is in fruit and vegetables processing (Artés et al., 2009). For plant surfaces treatment, recommended formulations combine H_2O_2 11% and CH_3CO_3H 15%, at 80 ppm, followed by rinsing with tap water (Suslow, 1997). It has been reported that it was effective for controlling *E. coli*, *Salmonella* spp. and *L. monocytogenes* in fresh-cut products (Park and Beuchat, 1999; Rodgers et al., 2004; Ruíz-Cruz et al., 2007; Abadías et al., 2011). Compared to 150 ppm NaClO, 80 ppm PA reduced the psychrotrophic counts by 2 log units and mesophilic counts by 1 log unit in fresh-cut 'Galia' melon, resulting in the pieces having a shelf-life of 10 days at 5 °C. However, this sanitizer decreased the total vitamin C and the antioxidant activity (Silveira et al., 2010). Vandekinderen et al., (2009) studied the impact of a decontamination step on the shelf-life, sensory quality and nutrient content of grated carrots under MAP

and stored at 7 °C. 80 mg/L PA showed possibilities for extending shelf-life without pronounced effects on nutritional content.

Recently, a novel sanitizer composed of lactic acid and PA (LA-PAA) was developed as an alternative to chlorinated water for fresh produce processing, resulting effective against *E. coli*, *Listeria innocua* and *Lactobacillus plantarum* on surfaces of spinach and Romaine lettuce (Grace et al., 2011). Silveira et al., (2011) tested the synergistic effect of hot water dipping (60 °C, 90 and 120s) followed by PA (80 mg/L) dip on metabolic activity and microbial growth in fresh-cut 'Galia' melon. As a main conclusion, this study provided a metabolic and microbial growth inhibition without affecting the sensory quality.

10.3.1.2 Chlorine dioxide Chlorine dioxide (ClO_2) has been proposed as an emerging sanitizer alternative to chlorine for the fresh and fresh-cut produce industry (Artés et al., 2009; Gómez-López et al., 2009). ClO_2 used as a disinfectant has several advantages over chlorine, including higher oxidant capacity (Benarde et al., 1967), lower reactivity with organic matter (Gordon and Rosenblat, 2005) and high effectiveness at low concentrations (Huang et al., 1997). In addition, ClO_2 and its main by-product, chlorite (ClO_2^-), are classified as non-carcinogenic products (EPA, 2000; IARC, 1991). However, like other chemicals used for process water and wastewater disinfection, ClO_2 has disadvantages associated with its use. ClO_2 is a very unstable substance; highly explosive as a concentrated gas (and therefore must be generated on-site). It decomposes readily when exposed to sunlight, as may occur in raw produce washing operations (Suslow, 1997).

Regardless of these practical challenges, the efficacy of ClO_2 in deactivating key food borne pathogens of concern among different commodities has been reported. Concentrations of 4–5 mg/L were effective to reduce *Salmonella* spp, *Escherichia coli* O157:H7 and *Listeria monocytogenes* inoculated onto cabbage, carrot, lettuce, strawberry and melon (Mahmoud and Linton, 2008; Keskinen et al., 2009). ClO_2 can also decrease the viability of *Cryptosporidium parvum* oocysts (Peeters et al., 1989). López-Gálvez et al. (2010) demonstrated that the use of aqueous 3 mg/L ClO_2 was equally effective as 100 mg/L NaClO and it did not cause any detrimental effect on the sensory and nutritional quality of fresh-cut iceberg lettuce without the potential formation of THMs. However, inconsistent results have been reported depending on the commodity, initial inoculum level, ClO_2 concentration, contact times washing conditions and recovery procedures (Singh et al., 2002; 2003; Lee and Baek, 2008; Pao et al., 2009).

Tomás-Callejas et al. (2012) evaluated NaClO and ClO_2 effectiveness to prevent *Escherichia coli* O157:H7 and *Salmonella* cross contamination on fresh-cut red chard. Typical industry rates of 20 mg/L NaClO (pH 6.5) and 3 ppm ClO_2 used in this experiment were unable to fully disinfect the applied pathogen surrogates from inoculated leaves regardless of the washing type.

While ClO_2 substantially prevented *E. coli* O157:H7 cross-contamination, of the isolate used in this study, it was not effective for the *Salmonella* isolate.

10.3.1.3 Acidified sodium chlorite The US FDA approved formulations of acidified sodium chlorite (ASC) for use as secondary direct food additives permitted for human consumption and doses range from 500 to 1200 mg/L. The antimicrobial activity of ASC is attributed to the oxidative effect of chlorous acid ($HClO_2$), which is derived from the conversion of chlorite ion into its acid form under strong acidic conditions. It is hypothesized that the mode of action of ASC derives from the uncharged $HClO_2$, which is able to penetrate bacterial cell walls and disrupt protein synthesis (CFR, 2007).

The use of ASC has been widely studied as a sanitizer for the meat industry (Castillo et al., 1999; Hajmeer et al., 2004) as compared to the limited research on fresh-cut produces. Inatsu et al. (2005a) evaluated the efficacy of ASC for reducing pathogenic bacteria on lightly fermented Chinese cabbage leaves. Washing inoculated leaves with distilled water reduced the population of *E. coli* O157:H7 by less than 1 log CFU/g, whereas treating with 0.5 g/L ASC reduced the population by more than 2 log CFU/g. In the same way, Allende et al. (2009) found reductions of 3 log CFU/g for *E. coli* O157:H7 populations on fresh-cut cilantro after washing with 1000 mg/L ASC compared to control. A reduction of viable aerobes of 1 log CFU/g for fresh-cut cantaloupes treated with 1 g/L ASC has been recently reported (Fan et al., 2009). Washing Chinese cabbage leaves with distilled water could reduce the population of *E. coli* O157:H7 by approximately 1 log CFU/g, whereas treating with 0.5 g/L ASC at 4 °C could reduce the population by 1.6 log CFU/g (Inatsu et al., 2005b). Recently, Tomás-Callejas et al. (2011b) published a study regarding the decontamination efficacy and quality attribute effects of ASC on fresh-cut tatsoi baby leaves after application and during storage. Low to moderate doses of ASC (100 to 500 mg/L) showed an initial antimicrobial efficacy on natural microflora and *Escherichia coli* as effective as that of NaClO. Regarding contact time, ASC was effective in reducing the *E. coli* population during the first 30 s of washing, and an increase in contact time did not improve the antimicrobial effect.

10.3.1.4 Hydrogen peroxide Hydrogen peroxide (H_2O_2) is a commercial sterilizing agent which has been widely used in the food industry and has been approved by the US FDA (Demirkol, 2009). It is considered a powerful bactericide, being effective even against spores. It is unstable and decomposed upon standing, agitation and exposure to light or heating, producing water and O_2. However, H_2O_2 is also able to generate other cytotoxic oxidizing species like hydroxyl radicals (Khadre and Yousef, 2001). An antimicrobial efficacy of H_2O_2 has been demonstrated in extending shelf-life and reducing native microbial and pathogen populations, including *E. coli*, in whole grape, prune, apple, orange, mushrooms, melon, tomato, red bell pepper and lettuce, and in

fresh-cut cucumber, zucchini, bell peppers and melons (Sapers, 2003; Artés et al., 2009).

For disinfection of fresh-cut commodities, the use of a diluted H_2O_2 solution has shown to be promising. For example, washing with 5% H_2O_2 was more effective than with 100 ppm NaClO and Na_3PO_4 for reducing the microbial load on cantaloupe rinds, thus improving microbial quality and shelf-life (Sapers and Simmons, 1998). Residual H_2O_2 in treated fruit and vegetables might be eliminated passively by the action of endogenous catalase, given enough time for reaction, or actively by rinsing immediately after treatment to avoid reactions between H_2O_2 and food constituents that might affect product quality or safety. Ukuku (2004) studied the effect of H_2O_2 on microbial quality and appearance of whole and fresh-cut melons contaminated with *Salmonella* spp. H_2O_2 treatments of whole melon (2.5% and 5%) for 5 min caused a 3 log CFU cm^{-2} reduction of the indigenous surface microflora and 3 log CFU cm^{-2} reduction in *Salmonella* in all melon surfaces. However, browning of shredded lettuce increased after dipping in a H_2O_2 solution (Parish et al., 2003).

Pedahzur et al. (1997) noticed an increase in the bactericidal effect of H_2O_2 and silver on E. coli when applied together, suggesting that such increase in the bactericidal effect of these two disinfectants might be due to the synergism between the two chemicals. Gopal et al. (2010) examined the use of silver and H_2O_2 as possible alternatives to NaClO. Combination of electrochemically generated silver (5 ppm) and H_2O_2 (0.4 ppm) caused a reduction in the total plate count (0.87 log), *Pseudomonas* (2.66 log), *Enterobactericeaea* (1.61 log) and yeast and mould (1.60 log) immediately after washing in comparison to water-washed shredded lettuce. The combination of 1% H_2O_2 with 25 μg/mL nisin, 1% sodium lactate, and 0.5% citric acid (HPLNC) for reducing transfer of bacterial pathogens from whole melon surfaces to fresh-cut pieces has been tested. HPLNC reduced the number of *E. coli* O157:H7 and *L. monocytogenes* by 3 to 4 log CFU cm^{-2} on melon and the natural microflora on fresh-cut melons were also substantially reduced (Ukuku et al., 2005).

The use of H_2O_2 as vapour instead of water solutions also appears to reduce microbial counts, extending shelf-life and maintaining quality of fresh-cut green bell pepper, cucumber and zucchini (Sapers, 2003). In this way, Li et al. (2011) tested the use of vaporized H_2O_2 alone or in combination with UV light for the inactivation on murine norovirus 1 (MNV-1) and bacteriophages (X174 and B40-8) on fresh-cut iceberg lettuce. This result concludes that the utilization of vapourized H_2O_2 in combination with UV light is promising for decontamination of fresh produce with much less consumption of water and disinfectant.

10.3.1.5 Organic acids Among the several natural approaches, citric and ascorbic acids were also frequently proposed to reduce microbial populations (Corbo et al., 2010). The antimicrobial action of these organic acids is due to pH reduction in the environment, disruption of membrane transport and/or

permeability, anion accumulation, or a reduction in internal cellular pH by the dissociation of hydrogen ions from the acid. More specifically citric acid has been accepted as effective in reducing superficial pH of cut fruit such as orange, apple, peach, apricot, kiwifruit, avocado and bananas (Soliva-Fortuny and Martín-Belloso, 2003).

The sanitizing efficacy of malic acid and ozone on artificially inoculated radish (*Raphanus sativa*) and moong bean (*Phaseolus aureous*) sprouts was determined against *Shigella* spp. Malic acid and ozone alone reduced the pathogen populations less than 3 log in both sprouts following complete immersion and spraying. Whereas, combination of both the sanitizers reduced pathogen populations by 4.4 log in radish and 4.8 log in bean sprouts (Sigla et al., 2011).

Fresh-cut Amarillo melon dipped in 0.52 mM citric acid for 30 s before MAP reached a shelf-life of 10 days at 5 °C. This treatment kept microbial safety and avoided translucency and discolouration. Compared to 1.4 mM NaClO, citric acid increased lightness and improved visual appearance of melon pieces (Aguayo et al., 2003). Dipping green celery crescents in a 0.5 M ascorbic and 0.1 M citric acid solution was as effective as 100 ppm NaClO for reducing microbial counts and improving consumer acceptability (Gómez and Artés, 2004). Ölmez and Temur (2010) investigated the effects of 0.25 g/100 g citric acid + 0.50 g/100 g ascorbic acid solution for 2 min at 10 °C on biofilms and attachment of *E. coli* and *L. monocytogenes* on green leaf lettuce. The treatment was unable to efficiently reduce or detach bacterial cells inside the biofilms or those cells attached to inaccessible sites. Moreover, a better understanding of the mechanism involved in bacterial attachment and biofilm formation is needed.

The effects of organic acids (lactic acid, citric acid, malic acid, tartaric acid and acetic acid) and hydrogen peroxide alone and in binary combinations with or without mild heat (40 and 50 °C) on the inactivation of *E. coli* O157:H7 on baby spinach have been investigated according to the principle of 'hurdle technology'. Washing with 1% lactic acid at 40 °C for 5 minutes was the most effective treatment achieving a 2.7 log reduction of *E. coli* O157:H7 which is significantly higher than chlorine (Huang and Chen, 2011).

10.3.1.6 Electrolyzed water Electrolyzed water (EW), both acidic (AEW) and neutral (NEW) types, has been proposed as a new sanitizer for the food industry (Izumi, 1999; Liao et al., 2007; Rico et al., 2008a; Tomás-Callejas et al., 2011c). EW is generated by electrolysis of a dilute salt (NaCl, usually about 0.1%) solution of pure water in an electrolysis chamber where anode and cathode electrodes are separated by a membrane. On the anode side, AEW is generated and has a strong bactericidal effect on most known pathogenic bacteria, due to its low pH, high oxidation–reduction potential (ORP) (about 1100 mV) and the presence of hypochlorous acid. The cathode area produces alkaline reducing water (Ongeng et al., 2006).

The main advantage of EW is its safety. In contrast to NaClO, AEW and NEW are not corrosive to skin, mucous membranes, or organic material. In addition, when EW comes in contact with organic matter, or is diluted by tap water or reverse osmosis water, it becomes ordinary water again. Thus, it is more eco-friendly than NaClO and is not potentially harmful for human health (Huang et al., 2008). A theory for inactivation of bacteria by EW was reported by Liao et al. (2007) on *E. coli* O157:H7. The inactivation mechanism proposed is that ORP could first affect and damage the redox state of glutathione disulfide–glutathione couple (GSSG/2GSH), and then penetrate the outer and inner membranes of *E. coli* O157:H7 resulting in the bacteria necrosis.

The use of AEW and NEW as disinfectants for food processing equipment has been studied (Park et al., 2002; Guentzel et al., 2008). Ayebah and Hung (2005) reported that AEW did not have any adverse effect on stainless steel. However, issues such as gas emission, strong acidity, metal corrosion, free chlorine content and formation of by-products need to be supported with further research.

The efficacy of NEW and AEW to reduce natural microflora as well as the main food-borne pathogens associated with a few fresh-cut plant products has been studied. The effects of NEW and AEW on physiological, nutritional, enzymatic, sensory and microbial during the shelf-life of fresh-cut mizuna baby leaves has been reported. Washing mizuna baby leaves with EW (40, 70 and 100 mg/L) inhibited the natural microflora growth and did not affect the surface structure of the leaves while the main quality attributes were kept for up to 11 days at 5 °C (Tomás-Callejas et al., 2011c). The use of AEW resulted in moderate control of bacterial growth on fresh-cut cilantro during storage (Wang et al., 2004). Reductions of viable aerobes by 2 log CFU g^{-1} were reached in lettuce washed with AEW (pH 2.6; ORP 1,140 mV; 30 mg/L of free chlorine) for 10 min (Koseki et al., 2001a). Also AEW was effective in reducing *E. coli* O157:H7 (Sharma and Demirci, 2003; Liao et al., 2007; Stopforth et al., 2008), *Salmonella* and *L. monocytogenes* (Venkitanarayanan et al., 1999; Fabrizio and Cutter, 2003; Stopforth et al., 2008). Compared to AEW, NEW could be less aggressive in relation to the corrosion of processing equipment due to its neutral pH. NEW (pH 6.8) containing 15–50 mg L^{-1} of available chlorine was effective as a disinfectant for fresh-cut vegetables without causing discolouration; NEW did not affect tissue pH, surface colour or general appearance (Izumi, 1999). Abadías et al. (2008) demonstrated that the bactericidal activity of diluted NEW (50mg/L free chlorine, pH 8.6) against *E. coli* O157.H7, *Salmonella*, *L. innocua* and *Erwinia carotovora* on fresh-cut lettuce was similar to that with NaClO (120 mg L^{-1} free chlorine).

10.3.1.7 Ozone O_3 was approved for use as a disinfectant or sanitizer in foods and food processing in the US (FDA, 1997). Ozone is a gas at room temperature formed by the highly unstable tri-atomic oxygen molecule (O_3)

obtained from the addition of an oxygen atom ($O^{\bullet}$) to a molecular diatomic oxygen (O_2) (Horvath et al., 1985). The gas is colourless with a pungent odour readily detectable at concentrations as low as 0.02 to 0.05 ppm, which is below levels of health concern. It is a powerful oxidant, second only to the hydroxyl free radical, among chemicals typically used in water treatment. Therefore, it is capable of oxidizing many organic and inorganic compounds in water.

Ozone is scarcely soluble in water and, even when it is more soluble than O_2, NaClO is 12 times more soluble than O_3. Basic chemistry research has shown that O_3 decomposes spontaneously during water treatment by a complex mechanism that involves the generation of hydroxyl free radicals (Glaze, 1987) which are among the most reactive oxidizing agents in water. The decomposition of O_3 is so rapid in the water phase of food that its antimicrobial action may take place mainly at the surface, leaving no residues. The bactericidal effects of O_3 have been shown on a wide variety of $Gram^+$ and $Gram^-$ bacteria as well as spores and vegetative cells (Foegeding, 1985). O_3 destroys microorganisms by the progressive oxidation of vital cell components, preventing the microbial growth and extending the shelf-life of many fruit and vegetables, and their industrial use is increasing (Parish et al., 2003). No significant effect of temperature on the efficacy of O_3 has been noted in the range of 10–26 °C (Ölmez and Akbas, 2009b).

The efficacy of gaseous O_3, applied under partial vacuum in a controlled reaction chamber, for the elimination of *Salmonella* inoculated on melon rind has been investigated (Selma et al., 2008). Gaseous O_3 (10 000 ppm for 30 min under vacuum) reduced viable, recoverable *Salmonella* from inoculated melons with a reduction between 4.2–2.8 log CFU/rind-disk (12 cm^2). A novel O_3 generation system capable of generating O_3 inside a sealed package at various geometries has been developed. Whole prepackaged spinach leaves inoculated with *E. coli* O157:H7 under this O_3 generation system showed a reduction in *E. coli* O157:H7; however, minimizing quality changes after treatment requires further research (Klockow and Keener, 2009).

Regarding O_3 handling, even when it has been approved as food additive, workers who might have contact with O_3 must be careful since gas concentrations over 0.2 ppm may affect RR and may produce dizziness and eyes and throat irritation (Hoof, 1982). Ambient O_3 levels at the industry facilities should be continuously monitored.

Inoculating targeted microorganisms on pure cell suspensions or on the food surface and treating these surfaces with O_3 under conditions that simulate normal processing has been useful for studying the efficacy of O_3 water. In that way some authors (Restaino et al., 1995; Singh et al., 2002) have found a decrease in pathogens including *S. aureus*, *S. typhimurium*, *Y. enterocolitica*, *L. monocytogenes* and *E. coli* O157:H7. The use of 1.5 ppm O_3 water (pH = 6 at 25 °C) for 15 s reduced between 1.5 and 5 log CFU g^{-1} *E. coli* O157:H7, *P. fluorescens*, *L. mesenteroides* and *L. monocytogenes* counts (Kim et al., 1999b).

Food composition may have a significant effect on the bactericidal power of O_3 against spore former, a Gram$^-$ rod and a Gram$^-$ cocci (Guzel-Seydim et al., 2004). O_3 may have a positive influence on some unwanted changes like Zhang et al. (2005) reported for celery sticks. In this case, dipping 0.18 ppm O_3 water for 5 minutes reduced RR, inhibited browning and improved sensory quality. Rico et al. (2006) found that ozonated water (1 mg/L at 18–20 °C) reduced both enzyme activity and enzymatic browning of shredded lettuce. However, this enzyme inactivation showed a negative effect, as the reduction in activity of the texture-related pectin methyl esterase was correlated with a lower crispiness. Selma et al. (2007) treated shredded lettuce with 5 ppm O_3 water for 5 min reaching a reduction of 1.8 log CFU/g in *Shigella sonnei* counts. In sliced 'Thomas' tomato stored for 10 days at 5 °C, the O_3 water (3.8 ppm, 3 min) reduced on 1.9, 1.6 and 0.7 the mesophilic, psychrotrophic and yeast counts respectively (Aguayo et al., 2006). In shredded iceberg lettuce, Baur et al. (2005) maintained better sensory and microbiological quality, prolonging shelf-life, in samples treated with 200 mg/L free chlorine than in O_3 water (1 ppm, 4 °C, 120 s). In contrast, the application of 2 ppm O_3 water for 2 minutes was found to be optimum processing conditions of shredded green leaf lettuce, in terms of reducing microbial load and maintaining the sensory quality compared with 100 ppm NaClO water during chilling storage (Ölmez and Akbas, 2009b).

10.3.2 Heating: hot water, steamer jet-injection

The use of hot water or steam has been tested as an alternative to replace chlorine as an environmentally friendly technology. Nevertheless, even when high temperatures may destroy microorganisms and inactivate enzymes, it can also alter sensory quality and reduce the content or bioavailability of some nutritional and health promoting compounds.

Hot water could be useful in cleaning and disinfecting whole melons to be fresh-cut processed without affecting quality. Naturally infected 'Galia' melons were artificially inoculated with *E. coli* for evaluating the potential of hot water rinsing and brushing (HWRB) technology to clean and disinfect the fruit. Treating melons with HWRB at 75 °C for 20 s reduced total microbial counts by 4 logs 4 days after treatment. Although, 75 °C for 20 s severely damaged the fruit peel if the fruit was left in storage, none of the HWRB treatments affected taste, aroma, colour or firmness of the flesh used for fresh-cut (Fallik et al., 2007). Another study with cantaloupe melon indicates that the combination of hot-water (76 °C for 3 min.) with the exposition to 0.5 kGy of gamma radiation reduced the population of native microflora while maintaining the quality of the fresh-cut melon cubes (Fan et al., 2006). Hot-water has also been alternatively effective for disinfecting pathogenic bacteria in seeds for alfalfa sprout production. Hot-water treatments (85 °C for 9 s) were equally or more effective than 200 ppm calcium hypochlorite treatments,

yielding a reduction of 2 log CFU g^1. A greater reduction (4 log) was obtained by soaking the seeds prior to the heat treatments (Enomoto et al., 2002).

Exposure to steam must be during a short time period (5–10 s) as reported for fresh-cut lettuce (Martín-Diana et al., 2007). In this case, the RR of the product decreased and a partial inactivation of browning-related enzymes was observed. Moreover, mesophilic counts were as low as under chlorine. However, ascorbic acid and carotenoids content showed a reduction. In a subsequent study it was observed that the longest steam treatment (10 s) reduced and maintained lower mesophilic load than shorter treatments (5–8.5 s) (Rico et al., 2008b). However, decreases in vitamin C and carotenoids were detected in samples treated with longer treatments.

10.3.3 Biological compounds, natural microbiota and/or their antimicrobial products

Natural alternatives to chemical control for reducing microbial growth in fresh-cut commodities have a high interest. Commercial products based on natural biocide action are now present in the market. Lactate esters from lactic acid and alcohols, which have shown to be effective against *E. coli* (Heuvelink et al., 1999), organic acids and flavonoids, mainly based on extracts of citrus fruit, and lactoperoxidase, thiocyanate and hydrogen peroxide mixture, which has been shown to have a bacteriostatic effect on gram-positive and a bactericide effect on $gram^-$ bacteria (Le-Nguyen et al., 2005), are some examples of the lately released alternatives.

Essential oils have been recognized as antimicrobial from ancient times and scientific confirmation has been reviewed recently. When applied on minimally processed table grapes, eugenol (from clove and basil) and thymol (from thyme and oregano) have exhibited antioxidant and antimicrobial effects (Burt, 2004; Valero et al., 2006). Essential oils could transfer off-odours to the produce. Moreover, at high doses, they may be hepatotoxic (Fujisawa et al., 2002). Careful studies are necessary for optimizing its application. At the right dose instead of simply preventing microbial growth they also may confer benefits for consumers' health due to its anti-inflammatory and antioxidant properties for humans (Gutiérrez et al., 2009). Milk whey permeated at different concentrations was used as a natural sanitizing agent for fresh-cut lettuce and carrots (Martín-Diana et al., 2006).

Natural competitive microbiota, in most of the cases lactic acid bacteria (LAB) and their derived antibacterial products, could also have an effect on controlling microbial growth in fresh-cut products. It has been observed in vegetables (Bari et al., 2005) and apples (Leverentz et al., 2006). Trias et al. (2008) observed that 23 of 496 LAB strains isolated from fresh-cut fruit and vegetables had high inhibitory abilities against food-borne and spoilage microorganisms. The high number of Leuconostoc strains (12) with biocontrol

potential was of particular interest. Remaining isolates were identified as *Lactobacillus plantarum* (6), *Weissella cibaria* (2), *Lactococcus lactis* (2) and *Enterococcus mundtii* (1). Organic acids, hydrogen peroxide and bacteriocins were detected as the main antimicrobial substances produced by these isolates, acidification being the most common inhibition mechanism. *Ex vivo* studies indicated that inhibition could be related to biofilm formation since LAB grew well on vegetable surfaces, although final population levels were considerably higher in fresh-cut lettuce than in apple wedges. One of the strains (*Leuconostoc mesenteroides*) was selected for its inhibition of *L. monocytogenes*. Future research is needed on this promissory control mechanism.

10.3.4 Pre-packaging (UV-C; intense light pulses)

The use of non-ionizing ultraviolet (UV) light at a wavelength of 190–280 nm (UV-C) seems to be promising for sanitizing purposes. A non-ionizing radiation is electromagnetic radiation that does not carry enough energy/quanta to ionize atoms or molecules and is represented mainly by UV rays, visible light, microwaves and infrared. Inactivation of microorganisms by UV irradiation is primarily due to DNA damage, which destroys the reproductive capabilities and other functions of the cell (Kuo et al., 1997). Lado and Yousef (2002) reported that UV-C radiation from 0.5 to 20 kJ m^{-2} inhibited microbial growth by inducing the formation of pyrimidine dimers killing those cells unable to repair radiation-damaged DNA while sublethally injured cells are often subject to mutations.

Losses of bioactive compounds are subtle since treatments do not substantially raise the temperature of food during processing (Wood and Bruhn, 2000). Alothman et al. (2009) showed that total phenol and flavonoid contents of guava and banana increased with the treatment time (mean of 2.15 kJ/m^2). In pineapple, there was no increase in total phenol content, but the flavonoid content increased after 10 minutes of treatment. In contrast UV-C treatment decreased the vitamin C content of all three fruits. UV-C treated watermelon cubes preserved their initial lycopene content with 2.8 kJ/m^2, or it was slightly decreased with a lower dose (1.6 kJ/m^2). In this experiment, control cubes showed a 16% decrease in lycopene content after 11 days at 5 °C. However UV-C radiation did not significantly affect the vitamin C content (Artés-Hernández et al., 2010). López-Rubira et al. (2005) showed insignificant changes in anthocyanins and antioxidant activity of pomegranate arils after exposure to UV-C (0.56–13.62 kJ/m^2). Fresh-cut mangoes which were UV-C radiated showed an increase in phenolic compounds and flavonoid contents with both 2.46 and 4.93 kJ/m^2, while both β-carotene and ascorbic acid decreased (González-Aguilar et al., 2007). Fan et al. (2003) reported that the free radicals generated during irradiation might act as stress signals and may trigger stress responses in lettuce, resulting in an increased antioxidant

synthesis. Irradiation of plant tissues with UV has been shown to have positive interactions, indicating an increase in the enzymes responsible for flavonoid biosynthesis, affecting plant phenolic metabolites apart from induction of abiotic stress. Even UV-A has been reported to induce anthocyanin biosynthesis in cherries (Kataoka et al., 1996). Finally, broccoli exposed to growing UV-C doses (1.5, 4.5, 9.0 and 15 kJ/m^2) had an increased total polyphenols content (up to 25%) after 19 days at 5 °C compared to the initial value. All the hydroxycinnamoyl acid derivates were immediately increased after UV-C treatments, with values 4.8- and 4.5-fold higher for 4.5 and 9.0 kJ UV-C m^{-2} treated samples respectively over the control. At the same time, total antioxidant activity generally followed the same pattern: the higher the UV-C doses the higher total antioxidant capacity values (Martínez-Hernández et al., 2011). It is quite evident that, apart from the application of UV for microbial safety at industrial levels, this novel technology has, with some exceptions, some potential in enhancement of health promoting compounds (Rawson et al., 2011).

A UV energy treatment offers several advantages to food processors as it does not leave any residue, does not have legal restrictions; it is relatively easy to use and lethal to most types of microorganisms (Bintsis et al., 2000; Yaun et al., 2004). For example, after 11 days at 5 °C, mesophilic, psycrophilic and enterobacteria populations were significantly lower in UV-C treated watermelon cubes (doses from 1.6 to 7.2 kJ/m^2) than in the untreated (Artés-Hernández et al., 2010). Studies performed on fresh-cut broccoli, low and moderate UV-C doses (1.5 and 4.5 kJ/m^2) had inhibitory effects on natural microflora growth (Martínez-Hernández et al., 2011).

Gardner and Shama (2000) demonstrated the efficiency of UV-C radiation on microbial inhibition by carrying several *in vitro* studies. Moreover, some strains could be more sensitive than others, as indicated by Abshire and Dunton (1981). Effectiveness of UV-C is independent of the temperature when it ranges from 5 to 37 °C but it depends on the structure and surface of treated product which determine the amount of incident radiation that really reach the produce (Bintsis et al., 2000; Lado and Yousef, 2002). UV-C acts also indirectly by stimulating plant defence mechanisms. Moreover, UV-C can change the cell permeability on leafy vegetables increasing electrolytes, aminoacids and carbohydrates leakage, which can stimulate bacterial growth (Nigro et al., 1998). The clue is to find a safe dose which would greatly weaken pathogen growth without being detrimental for the product (Ben-Yehoshua and Mercier, 2005).

Some *in vivo* studies have reported that UV-C inhibited microbial growth, delaying decay and senescence. In zucchini squash slices UV-C exposition (0.49, 4.9 and 9.8 kJ/m^2) reduced microbial activity and deterioration during subsequent storage at 5 or 10 °C (Erkan et al., 2001). Similar results were found for tomato (Lu et al., 1987; Liu et al., 1993), strawberry (Marquenie et al., 2002), carrot (Mercier and Arul, 1993), table grape (Nigro et al., 1998)

and sweet-potato (Stevens et al., 1999). It has been shown that 4 to 14 kJ UV-C/m^2 applied to broccoli heads delayed yellowing and chlorophyll degradation at 20 °C, displayed lower RR, and increased total phenols and flavonoids, along with higher antioxidant capacity (Civello et al., 2006).

UV-C radiation at 1.18, 2.37 or 7.11 kJ/m^2 applied at both sides of the product was effective for reducing the natural microflora of fresh-cut 'Red Oak Leaf' lettuce stored up to 10 days at 5 °C. However the highest dose induced tissue softening and browning after 7 days at 5 °C (Allende et al., 2006). Similar results were previously found for one sided UV-C radiation of fresh-cut 'Red Oak Leaf' and 'Lollo rosso' lettuces throughout 10 days at the same temperature (Allende and Artés, 2003ab). Radiation from 0.4 to 8.14 kJ/m^2 decreased yeast growth and psychrotrophic and coliform bacteria, but only significant reductions were found when the highest level was applied. Nevertheless due to reduced growth of competitive flora, the growth of LAB seemed to be stimulated by UV-C. Contradictory results were found by López-Rubira et al. (2005) when considered the effect of UV-C on microbial growth in fresh-cut pomegranate arils stored up to 15 days at 5 °C. UV-C doses from 0.56 to 13.62 kJ/m^2 did not affect RR, but some of them reduced mesophilic, psychrotrophic, LAB and enterobacteriaceae counts. Microbial counts were not always reduced throughout shelf life and yeast and moulds were unaffected. Artés-Hernández et al. (2009) found that while UV-C from 4.64 to 11.35 kJ/m^2 reduced the initial mesophilic and psychrophilic counts on the processing day, no residual effect was found after 6–13 days at 5 and 8 °C.

Pulsed light is a novel technique that rapidly inactivates pathogenic and food spoilage microorganisms. It appears to constitute a good alternative or a complement to conventional thermal or chemical decontamination processes. Intense light pulses (ILP) could be useful for decontamination of food surfaces including fresh-cut produces. It should be used during a short time period (from 85 ns to 0.3 ms) with high frequency pulses (from 0.45 to 15 Hz) and energy per pulse ranging from 3 to 551 J of an intense broad spectrum; rich in UV-C light (Gómez-López et al., 2005). Food components could absorb the effective wavelengths and decrease their efficiency. ILP has been used to successfully inactivate *E. coli* O157:H7 on alfalfa seeds (Sharma and Demirci, 2003) and *A. niger* spores on corn meal (Jun et al., 2003). Gómez-López et al. (2005) reported that foods rich in carbohydrate such as fruit and vegetables seem to be more suitable for decontamination by ILP, although an increase was found in the RR of treated fresh-cut produce. ILP did not prolong the sensory shelf-life of fresh-cut white cabbage or iceberg lettuce, while from the microbial point of view, one extra storage day at 7 °C was achieved for iceberg. The germicidal effect appears to be due to both photochemical and photothermal effects. It seems to induce structural changes of microbial DNA, comparable to the effect caused by continuous UV sources, but other mechanisms may be involved (Takeshita et al., 2003). Several high intensity flashes of broad spectrum light pulsed per second can inactivate microbes rapidly and

effectively. However, the efficacy of pulsed light may be limited by its low degree of penetration, as microorganisms are only inactivated on the surface of foods or in transparent media such as water (Elmnasser et al., 2007).

10.3.5 Packaging in superatmospheric oxygen and unconventional gas mixtures

Modified atmosphere storage under superatmospheric O_2 concentrations has been shown as effective to reduce aerobic and anaerobic microbial growth, prevent anaerobic fermentation, avoid undesirable flavour changes (Day, 2001) and inhibit enzymatic browning (Gómez et al., 2006). Since the studies about the use of this technique on different plant commodities started in the 1990s (Amanatidou et al., 1999 and 2000), the use of high O_2 in MAP is still incipient and needs to be supported by more research. In fact, the exposure to superatmospheric O_2 may stimulate, have no effect, or reduce RR and C_2H_4 production, depending on the commodity, ripening stage, O_2 level, storage time and temperature, and CO_2 and C_2H_4 levels in the atmosphere (Kader and Ben-Yehoshua, 2000).

Jacxsens et al. (2001) reported a low sensitivity in grated celeriac and shredded chicory endive. RR of grated celeriac reached 120, 97 and 124 nmol at 3, 80 and 95 kPa O_2, O_2 kg^{-1} s^{-1} respectively. For shredded endive it was 90, 107 and 132 nmol O_2 kg^{-1} s^{-1} also respectively. In addition, exposure of fresh-cut carrot to 50 kPa O_2 + 30 kPa CO_2 showed an accelerated C_2H_4 production, possibly as an injury response at 8 °C after 2 to 3 d (Amanatidou et al., 2000). At levels above 80% O_2 some commodities and postharvest pathogens suffer from O_2 toxicity (Kader and Ben-Yehoshua, 2000). Fresh-cut carrot initially stored under 70 kPa O_2 had a three-fold higher RR than under initial 2.5 kPa O_2 + 7 kPa CO_2, as a consequence of oxidative processes. By using low permeability film a rapid depletion of O_2 and accumulation of CO_2 was obtained under initial low O_2 concentration (Oms-Oliu et al., 2008a).

Exposure to high O_2 did not strongly inhibit microbial growth, while a high CO_2 reduced the growth to some extent in most cases. However, the combined high O_2 level and 10 to 20 kPa CO_2 may provide adequate suppression of microbial growth and prolong shelf-life (Allende et al., 2004; Geysen et al., 2006; Conesa et al., 2007ab; Escalona et al., 2007). Applying a high O_2 level in a high-barrier film showed a beneficial effect for lowering the microbial growth and keeping sensory attributes of raspberries and strawberries (Van Der Steen et al., 2002). Related to microbial growth, Allende et al. (2004) showed a reduction of aerobic microbial growth in superatmospheric O_2 applied in MAP using a barrier film due to the accumulation of high CO_2 levels. The addition of CO_2 is unnecessary when high O_2 atmospheres are injected in barrier film packages, because the respiratory activity of produces generate

antimicrobial CO_2 levels reaching 20 kPa. The antimicrobial activity of CO_2 at high level is already well known.

Levels higher than 75 kPa O_2 were needed to reduce *L. innocua* growth on fresh-cut lettuce (Escalona et al., 2007), in agreement with result of Geysen et al. (2006) which reported that *L. innocua* growth was not significantly influenced by O_2 levels up to 100 kPa.

Several factors may explain the toxicity of hyperbaric O_2 like the unfavourable effects on the oxidation-reduction potential of the system, the oxidation of enzymes having sulfhydryl groups or disulfide bridges, and the accumulation of injurious reactive O_2 species (Kader and Ben-Yehoshua, 2000). On the other hand, CO_2 causes a decrease in intra and extracellular pH and interferes with the cellular metabolism (Dixon and Kell, 1989). The inhibitory effect is stronger at low temperature because of enhanced CO_2 solubility.

High O_2 levels kept the initial colour and firmness of fresh-cut melon retarding anaerobic fermentation better than low O_2 concentrations. In addition, exposure to low and high O_2 levels delayed the yeast growth (Oms-Oliu et al., 2008b). Other reports showed that chemical parameters and surface colour of fresh Chinese bayberries, strawberries and blueberries stored in 40 to 100 kPa O_2 at 5 °C were slightly affected by the high O_2 level compared to air. However, the berries kept in 60 to 100 kPa O_2 showed inhibited decay and after an additional two days in air at 20 °C, treated fruit also exhibited less decay rate, suggesting that high O_2 levels had a residual effect on decay control (Zheng et al., 2008).

Gómez et al., (2006) examined the effects of elevated O_2 (from 5 to 100 kPa) on *in vitro* kinetics of PPO, main enzyme responsible for browning, and using chlorogenic acid as substrate. The substrate concentration as well as the O_2 level had a clear inhibitory effect on the reaction rate. Moreover, the inhibitory effect of O_2 was more evident at low final product concentration. V_{max} can be considerably delayed at high O_2 concentrations (Figure 10.2). In vivo studios indicated that an atmosphere of 80 kPa $O_2 + 20$ kPa CO_2 delayed browning of shredded lettuce under MAP for 10 d at 5 °C compared to air (Heimdal et al., 1995), although it is well known that browning susceptibility is highly cultivar dependent. In the same way, results with fresh-cut bell peppers from two *cvs.* grown under different conditions showed that 80 kPa O_2 combined with 15 kPa CO_2 maintained the main sensory quality attributes and inhibited growth of the spoilage microorganisms and *Enterobacteriaceae* (Conesa et al., 2007ab). Jacxsens et al. (2001) found that low O_2 caused a reduction in the enzymatic browning in fresh-cut vegetables since O_2 is a necessary substrate for the reaction. However, high O_2 atmospheres were more effective in reducing or inhibiting the enzymatic browning of iceberg lettuce, radicchio and lollo rosso lettuce. Day (2001) reported evidence of the effectiveness of high O_2 MAP on inhibiting iceberg lettuce enzymatic browning as well. It is hypothesized that high O_2 may cause substrate inhibition of

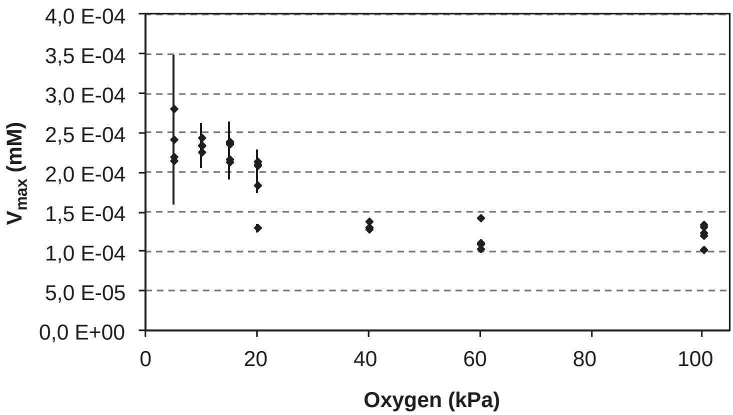

Figure 10.2 Estimation of V_{max} values of in vitro PPO activity as a function of initial O2 concentration, using chlorogenic acid as substrate (bars indicate 95% confidence limits).

PPO or, high levels of colourless quinones formed cause feedback inhibition of PPO. However Heimdal et al. (1995) found that fresh-cut iceberg lettuce under 80 kPa O_2 + 20 kPa CO_2 showed higher browning than under moderate vacuum MAP.

Lu and Toivonen (2000) reported that a pretreatment of the whole 'Spartan' apple with 100 kPa O_2 before cutting reduced surface browning, flesh softening, and off flavour in fresh-cut slices. This inhibition of browning was associated with retention of cellular integrity while in low O_2 pretreatment would have another inhibitory browning mechanism on apple slices. Therefore, the treatment with 100 kPa O_2 prior to slicing apples can reduce the dependence on antioxidant additives to inhibit slices browning.

Regarding sensory quality, acceptable scores were found in spinach leaves treated with 80 kPa O_2 + 20 kPa CO_2 compared to low O_2 and high CO_2, where the spinach was affected by fermentation (Allende et al., 2004). Beneficial effects of superatmospheric O_2 have been reported for shredded chicory endive and mixed vegetable salads (Jacxsens et al., 2001; Allende et al., 2002). Fresh-cut butter lettuce kept a good visual appearance with 75 kPa O_2 + 15 kPa CO_2 after 10 d at 7 °C, reducing cut surface browning and loss of freshness (Escalona et al., 2007). Fresh cut carrots stored in 50 kPa O_2 + 30 kPa CO_2 had similar or better quality than those in 1 kPa O_2 + 10 kPa CO_2 after 12 d at 8 °C. Therefore, fresh-cut carrots could tolerate high CO_2 levels in combination with high O_2 levels, and this innovative MAP can be used for keeping their fresh characteristics and lowering microbial growth during shelf life (Amanatidou et al., 2000).

MAP under non-conventional gases mixtures using Ar, He, Xe or N_2O could be an alternative to be used for fresh-cut products. Those gases may have a physiological effect as well as an effect on microbial growth (Gorny and

Agar, 1998). Low O_2 atmospheres combined with high Ar, He or N_2 had different diffusive properties since Ar and He are monoatomic and smaller in size than N_2 (Jamie and Saltveit, 2002). Asparagus spears treated for 24 h with a mixture 2:9/Ar:Xe at 4 °C had reduced bract opening and RR and could be kept in air for 12 days at 4 °C with better quality than those stored under a 5 kPa O_2/kPaCO_2 atmosphere (Zhang et al., 2008). He and O_2-enriched (>85 kPa O_2) MAPs were found to be useful tools in the preservation of fresh-cut red chard baby leaves quality up to 8 days at 5 °C by lowering natural microflora growth and preserving some health promoting compounds (Tomás-Callejas et al., 2011d).

N_2O has 77% solubility in fruit cell, although its absorption in tissues is completely reversible (Gouble et al., 1995). That is the possible reason because N_2O have a direct effect on cell metabolism extending produce shelf life. For minimally processed spinach leaves stored under N_2O-enriched MAP a reduced microbial growth has been observed after 8 days at 5 °C, preserving phenolics and chlorophylls (Rodríguez-Hidalgo et al., 2010). More research is needed to analyse the feasibility of applying these innovative atmosphere to fresh-cut produce.

10.4 Revalorization of fresh-cut by-products

The fresh-cut product industry generates high amounts of wastes (peels, seeds, peduncles, stones and unused flesh that are generated by different steps of the industrial process) and they constitute an important environmental problem. Over 1 million tonnes of vegetable trimmings from the vegetable processing industry are produced in the EU every year (Eurostat, 2005). Some whole fruit percentages of the unused by-products obtained in the fresh-cut industry are: sliced apples produce 10.91% of pulp and seed (core) by-products, diced papayas produce 6.51% of seed, 8.47% of peel, 32.06% of unusable pulp (due to the lack of shape uniformity in a cube), mangos produced 13.5% of seeds, 11% of peel, and 17.94% unusable pulp (Ayala-Zavala et al., 2010). Aguayo et al. (2004) reported an inedible portion of 47%, in fresh-cut melon of which 3.4% corresponded to the seeds and 43.7% to the peel. In watermelon, in which the seeds are distributed throughout the flesh, the edible portion is slightly higher and the amount of by-products was 31.27 to 40.61% depending on the cultivar (Tarazona-Díaz et al., 2011). These amounts of by-products will increase progressively as the fresh-cut industry keeps growing, and in the coming years, its disposal will be of primary concern. The integral exploitation of the entire plant tissue could have economic benefits to producers and a positive environmental impact leading to a greater diversity of products directed to human usage (Schieber et al., 2001). In fact, an interesting approach is to utilize by-products for their biological compounds such as natural antioxidants or functional ingredients to add to food products, and could represent a solution to the environmental problem. Functional foods try

to contribute to a proper dietary habit by providing foodstuffs with 'added-value': increasing natural health-promoting compounds in a specific source, removing undesirable components, adding new ingredients (modifying taste, colour, increasing health-promoting properties, etc.) or increasing bio-availability of active compounds, and so on (Roberfroid, 2000).

Numerous concepts related to the presence of antioxidants in foods and their potential health benefits to humans are becoming recognized. Several studies have shown that the content of phytochemical compounds is higher in peel and seeds with respect to the edible tissue. Peels from apples, peaches, pears as well as yellow and white flesh nectarines were found to contain twice the amount of total phenolic compounds as that contained in fruit pulp (Gorinstein et al., 2001). Other studies have reported that pomegranate peels contain 249.4 mg/g of phenolic compounds as compared to only 24.4 mg g^{-1} phenolic compounds found in the pulp of pomegranates (Li et al., 2005), and mango peel contains a number of valuable compounds such as polyphenols, carotenoids, enzymes, dietary fibre (Ajila et al., 2007) and pectin (Sirisakulwat et al., 2010). Apple peel is also rich in many health-enhancing phytonutrients including flavonoids and phenolic acids and rich as a source of dietary fibre (Boyer and Liu, 2004). Different authors have suggested the use of apple peel as a value added food ingredient (Wolfe and Liu, 2003).

Tomato industries are an example of the high amount of by-products produced, mainly as tomato peel and seeds. Tomato skin has 2.5 times higher lycopene levels than the pulp, with significant amounts of phenolics and ascorbic acid (George et al., 2004). Rozzi et al. (2002) studied supercritical fluid extraction to extract lycopene from tomato processing by-products resulting in the extraction of 61% of the lycopene (7.19 μg lycopene g^{-1}). Benakmoum et al. (2008) reported that enrichment of low quality oils like refined olive oils by adding tomato skin, enhancing the concentrations of β-carotene and lycopene, might be an alternative approach to elaborate new functional foods. Another example of new functional products obtained from vegetal byproducts is the 'functionalized' tomato juice using phenolic-enriched extracts from blanched artichoke, artichoke blanching waters, cauliflower, carrot, celery and onion by-products (Larrosa et al., 2002). The antioxidant activity of this functional tomato juice is significantly increased compared to control juices.

Research carried out on crude extracts obtained from hazelnut by-products by Shahidi et al. (2007) found that hazelnut wastes, especially skin and hard shell, were a reliable source of new and efficient natural antioxidants. The fresh date processing (picking, storage or conditioning) may also lead to date losses. Such by-products from fresh dates can be processed to prepare date paste with high content of sugars, total and insoluble dietary fibre, and natural antioxidants (Sánchez-Zapata et al., 2011). In the asparagus industry there is more than 30% by-product produced, mostly peel stem and crown. These by-products are a rich source of rutin and protodioscin which is the active

ingredient in the dietary supplement (Xiaoyan and Yue, 2010). Artichoke processing also generates high volumes of byproducts. Extract from the edible part and other artichoke parts are rich in polyphenols, and show a high antioxidant activity (Llorach et al., 2002). Isorhoifolin (apigenin-7-O-rutinoside), narirutin, cynarin (1,5-dicaffeoylquinic acid and 1,3-dicaffeoylquinic acid), chlorogenic acid, caffeic acid and cynaroside are identified in the different parts of the plant (Alamanni and Cossu, 2003). Llorach et al. (2002) found artichoke blanching water contained neochlorogenic acid, cryptochlorogenic acid, chlorogenic acid cynarin and caffeic acid derivatives. Currently artichoke extract, artichoke tea and artichoke wine are developed in different countries, artichoke capsule and artichoke cosmetics can also be found. Those kinds of products are made from artichoke by-products of the processing industry (Xiaoyan and Yue, 2010). Broccoli by-products, consisting of leaves and stalks, are rich in nitrogen–sulphur compounds (glucosinolates and isothiocyanates) and phenolics (chlorogenic and sinapic acid derivatives, and flavonoids), as well as essential nutrients (minerals and vitamins) (Jeffery et al., 2003). Domínguez-Perles et al. (2011) studied the fresh-cut broccoli by-products as a source of bioactive ingredients to design novel beverages, using organic green tea as a food matrix. Green tea enriched with broccoli concentrates showed improved physical quality, phytochemical composition and antioxidant capacity. Onion has also shown a variety of pharmacological effects such as growth inhibition of tumour and microbial cells, reduction of cancer risk, scavenging of free radicals, and protection against cardiovascular disease, which are attributed to specific sulfur-containing compounds and flavonoids (Ly et al., 2005). Specifically, onion has been characterized for its flavonol quercetin and quercetin derivates and it is rich in other bioactive compounds such as oligosaccharides and sulfur compounds. Roldán et al. (2008) obtained stabilized (mild pasteurization) onion by-products as a natural source of antioxidant and antibrowning bioactive compounds.

Dietary fibre concentrates from vegetables showed a high total dietary fibre content and better insoluble/soluble dietary fibre ratios than cereal brans (Grigelmo-Miguel and Martín-Belloso, 1999). A number of researchers have used fruit and vegetable by-products from apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, carrot pomace (Grigelmo-Miguel and Martín-Belloso, 1999; Nawirska and Kwasnievska, 2005) as sources of dietary fibre supplements in refined food. Cauliflower, which has a high waste index (Llorach et al., 2003), is considered to be a rich source of dietary fibre and possesses both antioxidant and anticarcinogenic properties. Stojceska et al. (2008) studied the incorporation of cauliflower by-products (trimmings) into ready-to-eat snacks. Dried and milled cauliflower by-products at levels of 5–20% were added to the formulation mix, increasing dietary fibre in the finished product by over 100%, and increasing protein content and water absorption index.

Fruits and vegetables by-products can also provide lipids and amino acids. Seeds from a melon hybrid 'ChunLi' contained high percentages of lipids (35% dw) and proteins (29.90 g/100 g dw), and the presence of 25 fatty acids, with the principal fatty acids linoleic, oleic, palmitic and stearic acids. Seed proteins were rich in arginine, aspartic and glutamic acids while amino acids as methionine and lysine were limited (Hu and Ao, 2007). It has also been reported that the watermelon seeds can be utilized successfully as sources of good quality oil and protein for human consumption (Akoh and Nwosu, 1992). In addition, watermelon skin, a typical by-product from the fresh-cut industry, is a rich source of biological amino acids (non-essential), such as citrulline (Rimando and Perkins-Veazie, 2005) with some cultivars, such as 'Fashion', containing more citrulline than others (7.5 g/kg fw) (Tarazona-Díaz et al., 2011). Citrulline is used in the nitric oxide system in humans and is an efficient hydroxyl radical scavenger, a strong antioxidant and it has vasolidatador roles (Ikeda et al., 2000).

Throughout the world, there is an increasing interest in the importance of dietary minerals in the prevention of several diseases such as cancer, diabetes, osteoporosis (Ozcan, 2004). Unpublished data of Tarazona and Aguayo showed the mineral composition of several by-products from fresh-cut products and found a high level of iron in potato peel (19 mg/100 g dw similar to cooked liver beef) and a Ca level (853.95 mg/100 g dw) in cucumber peel comparable to that of whole dry milk powder. Melon peel was rich in magnesium (465 mg/100 g dw) and watermelon peel was characterized by the level of potassium (4,773 mg/100 g dw).

10.5 Future research needs

The fresh-cut industry must look to optimize all processing operations involved in the production with safety being the main objective followed by quality and loss reduction. In this way, plant raw materials must be carefully chosen in regards to their ability to support the different processing steps. Also, secondary techniques for keeping quality attributes and safety while extending shelf life are needed. Safeguarding techniques must become milder in response to demand for less processed foods and less reliant on chemical preservatives (Abee and Wouters, 1999; Artés and Allende, 2005).

Among the preharvest plant raw materials safety priority research areas, Kader (2011) has selected the following:

- Critical factors must be defined for evaluating application of organic N sources to plant crops. The influence of crop, region, season, source, pathogen, and treatment or application time/method should be quantified.
- Practical improvements in composting process control or handling practices might result in more consistent inactivation of human pathogens that can be validated and monitored.

- Studies about factors influencing how food-borne pathogens can be transferred from animal operations to fruit or vegetable crops by the wind, insects and wildlife should be conducted.
- Other aspects which should be studied are the use of rubber gloves and their potential for transfer of soil and pathogens to hand harvested products, and potential risks of pathogen transference from contaminated plastic bins or harvest equipment to raw products and sanitation methods to reduce these risks.

At the postharvest step some priority research areas are as follows:

- Accurate control over wash water sanitation must be implemented. New improved tools to reliably monitor organic load must be developed.
- Cost-effective methods that would allow for quantification of pathogens on fruits or vegetables should be developed or adapted.

To guarantee the adequacy of safety measures greater interaction among multidisciplinary scientific teams should be promoted. Conventional and alternative preservation techniques and simulation modelling of quality and safety issues should be taken into consideration to build a global approach for assuring safety of fresh-cut food consumers. As end users need to be sure that the fresh-cut food they buy is safe and healthy the food industry is obliged to invest time, energy and resources in this way (Artés and Allende, 2005).

A more effective and sustainable approach against lack of safety of fresh-cut plant commodities needs to be addressed by using combined microbial control strategies based on emerging preservation techniques and traditional ones. Among the most useful tools improved genetic resistance to microbial pathogens, enhanced or new physical methods, low levels of GRAS antimicrobial substances authorized, natural compounds and/or microbial antagonists could be included. The particular hurdles techniques can be kept at their lowest doses for reaching the required response of exposed target microbial populations. Likewise, for keeping safety, some equivalent combinations could be determined by predictive models and computer simulations for enabling evaluation of the selected strategies and tools success for improving their efficacy. Genetic engineering technology is an effective way to introduce desirable attributes such as improved colour, flavour and taste or enhanced nutritive value into plant foods, although pathogen resistance has not been tackled yet. More research is needed and the new advances in functional genomics should provide candidate genes for manipulation.

Application of induced resistance methods to fresh-cut produce is an alternative biocontrol hurdle, as the cutting processes may induce an elicitor response. The efficacy of elicitors and the effects of treatment on the sensory quality of fresh-cut should be studied. In this way the biocontrol techniques will rely on basic research of the growth, interactions and biochemical activity

of associated microbial species and the mechanisms underlying their development.

More studies are needed to assess the effectiveness of the proposed sanitation alternatives compared to the current chlorine-based method. In this aim, the experiments should be conducted for each different kind of fresh-cut plant commodities and microbial pathogens under the most standardized testing protocols.

More emphasis will likely be directed toward surveying in the industrial factories the hygienic grade of plant raw materials entering the minimal processing chain and this involves mainly surveying both pathogenic bacteria and potential mycotoxin-producing fungi. This is particularly crucial for organically cultivated fruit and vegetables. The hygienic concept in the industrial project should be incorporated at all levels and steps.

The use of by-products is likely to increase in the near future, mostly due to the public appreciation of natural components as opposed to synthetic chemicals. Lots of work in the future is needed, about the extraction techniques of bioactive compounds from by-products and the design of new products with appropriate sensorial, functional and nutritional attributes and with a reasonable cost having the challenge of environmental protection.

Improved intelligent packs including security tags for monitoring the safety of fresh-cut produces can be very helpful in the distribution chain. In the same way research should be conducted into the identification of indicators for use in sensitive fresh-cut produces that would signal the occurrence of bacterial pathogens, and/or pathogenic viruses or parasites. These new packaging systems also create possibilities to minimize product waste by more efficient distribution (Artés et al., 2012).

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11 Sustainable Food Grain Processing

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11.1 Introduction

Sustainability issues concern the entire food production and supply chain, from agricultural production and processing to packing, distribution and final consumption. Each step along the chain involves the input of resources and generation of wastes and emissions. Historically, grains were processed with the aim of making it digestible either by resizing or removal of anti-nutrients. In the past, advances in grain processing allowed complete removal of covering from starchy endosperm of the grain, that is, only the starchy endosperm of the grain used for human consumption, but its co-products like husk, bran and germ are used for other purposes such as animal feed, oil extraction, and so on. However, whole grain (including bran, germ and endosperm) consumption is now recognized to receive the highest benefits with regard to the grain nutrients. In fact, bran and germ contain numerous amounts of essential macro- and micronutrients including proteins, peptides, amino acids, dietary fibers and can contribute to people's health and well-being.

It is obvious that feeding grains to the people rather than to livestock and poultry should be the choice for environmental and social sustainability as people fed on grain-based diets could become healthier at much lower environmental and social costs than on meat-based diets (Goodland, 1997). The sustainability debate on direct grain consumption versus conversion of

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grain into meat should be raised. For sustainability, eating lower on the food chain, that is, moving toward grain-based diets can reduce the environmental damage and suffering caused by overconsumption and excessive population. The links between dietary choice and environmental sustainability are becoming more evident. As reported by the UN World Food Council, 10–15% of cereal fed to livestock is enough to raise the world calorie supply to adequate levels (Goodland, 1997). It is also determined that one acre of cereals can produce twice to ten times as much protein as an acre in beef production and to a greater extent that one acre of legumes can produce 10 to 20 times more protein than an acre in beef production. Grain legumes are considered to be an important source of food protein, especially in developing countries. Preservation of grains' nutrients is rendered with the advancement of grain processing, hence a large number of grain products available for human consumption. With regard to a decrease in meat-based diets, textured vegetable protein made by an extrusion of soybean flour is valuable as a meat substitute.

Sundkvist et al. (2001) reported an analysis for the environmental consequences of small-scale versus large-scale bread production. Bread production in the small-scale bakery industry requires more total energy input per kg of bread than the medium and larger bakery industries. The main reason for this result is due to inefficient technology. On the other hand, the analysis shows that emission of CO_2, SO_2 and NO are smaller from bread produced in the small local bakeries than from big bakeries on the Swedish mainland. This is because the transportation routes are much shorter for bread from the small bakeries and because oil is more frequently used for heating the ovens in large and medium sized bakeries.

Microwave technology is considered to be green and sustainable because it is much more energy efficient than conventional heating and reaction methods and generally leads to much faster reactions and processing. Sripinyowanich and Noomhorm (2012) assessed the potential of a single-mode applicator-microwave-assisted vibro-fluidized bed (SMA-MVFB) dryer to produce instant rice. Energy consumption during drying could be reduced by increasing drying temperature and performing freezing pretreatment. Comparing between the energy required by SMA-MVFB and vibro-fluidized bed (VFB) drying, higher energy consumption was observed from VFB drying where the difference in drying periods between MVFB and VFB drying was higher than 30 s. The lowest energy of 0.193 kWh was required for MVFB drying of frozen cooked rice at 185 °C, whereas the highest energy of 0.523 kWh was required for VFB drying of unfrozen cooked rice at 110 °C.

Rice grain is one of the best examples of grains' versatility. Many processing techniques can be employed to manufacture rice grains with distinctive and various types of finished rice product obtained. In general, harvested rice is initially dried either by sun drying or oven drying to approximately 12% moisture. Then, dried rough rice or paddy is processed by various techniques as shown in Figure 11.1. In the same case of whole grain benefits, whole rice

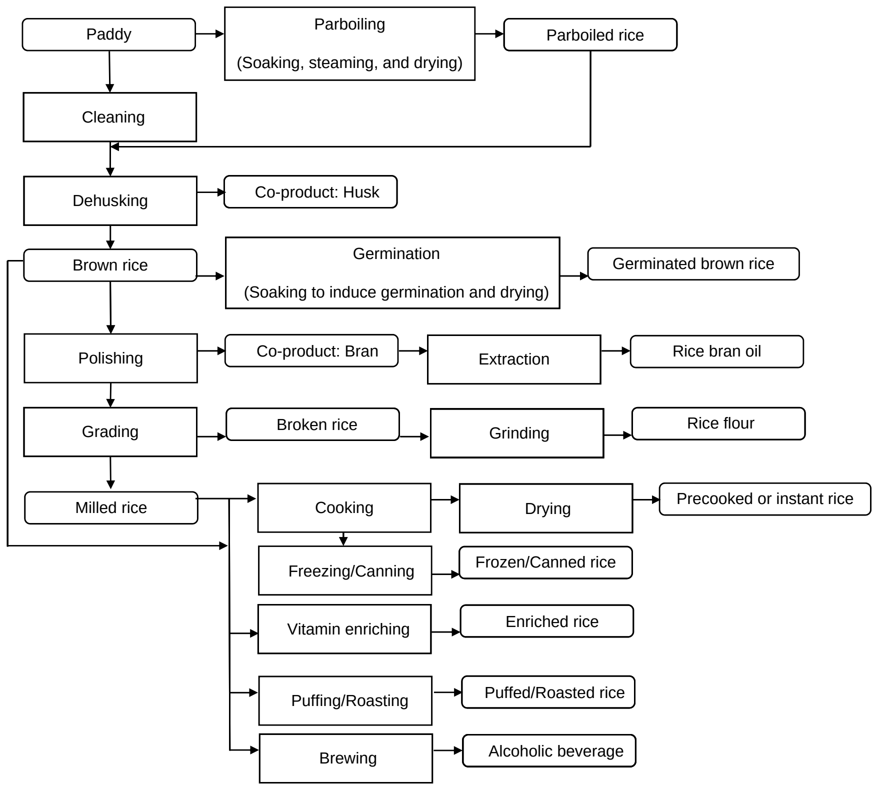

Figure 11.1 Rice processing and its co-products.

grain called brown rice has more protein, more fibre, and lower glycemic index as compared with milled rice containing only starchy endosperm. The gross composition of rice and its various milling fractions are given in Tables 11.1 and 11.2. Major nutrients in rice are accumulated in its co-products, not the starch endosperm. However, with the establishment of nutrient fortification process, white rice is enriched with various types of vitamins and minerals such as thiamin, folate and niacin.

Rice bran, which is the co-product of rice processing, is a rich source of nutrients such as oil (12%), fiber (14%), protein (12%) and ash (12%). Protein in rice bran is considered as a source of hypoallergenic protein. Many kinds of rice bran, such as full fatted, defatted, stabilized and unstabilized rice bran, can be used for protein extraction. An alkaline extraction-acid precipitation method is the most conventional method for extracting protein from rice bran (Bera and Mukherjee, 1989; Prakash and Ramanatham, 1995; Gnanasambandam and Hettiarachchy, 1995; Chandi and Sogi, 2007). An alternative method for the rice bran extraction (Parrado et al., 2006; Wang et al., 1999) is the enzymatic method.

Table 11.1 Approximated composition of paddy and its milling fractions at the moisture content of 14%w.b

Rice fraction	Crude protein (g N $\times$ 5.95)	Crude fat (g)	Crude fiber (g)	Crude ash (g)	Carbohydrates (g)	Neutral detergent fiber (g)
Paddy	5.8–7.7	1.5–2.3	7.2–10.4	2.9–5.2	64–73	16.4–19.2
Brown rice	7.1–8.3	1.6–2.8	0.6–1.0	1.0–1.5	73–87	2.9–3.9
Milled rice	6.3–7.1	0.3–0.5	0.2–0.5	0.3–0.8	77–89	0.7–2.3
Rice bran	11.3–14.9	15.0–19.7	7.0–1.4	6.6–9.9	34–62	24–29
Rice husk	2.0–2.8	0.3–0.8	34.5–45.9	13.2–21.0	22–34	66–74

Recently, subcritical water hydrolysis was used for the extraction but the process was done at high temperatures ($100° \leq T \leq 374.2\,°C$) (Sereewatthanawut et al., 2008). All of these extraction methods have low extraction rates and result in low yields, and some methods even deteriorate protein quality.

According to the study of Chittapalo (2010) the ultrasonication method instead of the time-consuming, conventional protein extraction. The extraction time using the alkaline conventional method was 60 minutes, while that using the ultrasonication method was 5 minutes at 100 W. The properties of defatted rice bran protein concentrate (DRBPC) obtained using the ultrasonic (100 W for 5 min) and conventional methods showed no significant difference in bulk densities ($P > 0.05$), but the yield using ultrasonication was higher, about 4.45 and 2.70% respectively. Furthermore, the size of the protein particles were bigger (observation by scanning electron microscopy) and lighter brown using the ultrasonication method. In terms of the functional properties of both samples, foam and emulsifying stability were not significantly different. On the other hand, the water and oil absorption using ultrasonication were higher than those using the conventional method, and the foam capacity and emulsion activity using the conventional method were higher than those extracted by ultrasonication method. The nitrogen solubility index of both DRBPC samples had similar profiles with the lowest solubility at pH 4-6.The predicted protein efficiency ratio (P-PER), Leu/Ile, and the difference between Leu and Ile were found to be similar in both types of extracts. The percentage of essential amino acids in the DRBPC sample using the ultrasonication method was higher than that using the conventional method at 52.46 and 47.36% respectively. The amino acid composition of the DRBPC samples was similar in acidic, basic and hydrophobic amino acid concentrations. The amino acid concentrations of methionine, cysteine and serine were higher using the conventional method. However, the concentration of uncharged polar amino acids of the DRBPC samples using the conventional method was higher than that using the ultrasonication method at 25.19 and 17.53 mg/100g of protein respectively.

Table 11.2 Vitamin and mineral contents of paddy and its milling fractions at the moisture content of 14%w.b

Rice fraction	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	α-tocopherol (mg)	Calcium (mg)	Phosphorous (mg)	Phytin P (mg)	Iron (mg)	Zinc (mg)
Paddy	0.26–0.38	0.06–0.11	2.90–5.60	0.90–2.00	10–80	0.17–0.39	0.18–0.21	1.40–6.00	1.70–3.10
Brown rice	0.29–0.61	0.04–0.14	3.50–5.30	0.90–2.50	10–50	0.17–0.43	0.13–0.27	0.20–5.20	0.60–2.80
Milled rice	0.02–0.11	0.02–0.06	1.30–2.40	75.0–0.30	10–30	0.08–0.15	0.02–0.07	0.20–2.80	0.60–2.30
Rice bran	1.20–2.40	0.18–0.43	26.7–49.9	2.60–13.3	30–120	1.10–2.50	0.90–2.20	8.60–43.0	4.30–25.8
Rice husk	0.09–0.21	0.05–0.07	1.60–4.20	–	60–130	0.03–0.07	–	3.90–9.50	0.90–4.00

One nutritionally superior method for preparing a nutrient-enhanced brown rice product is a germination process, generally designated as germinated brown rice (GBR). During germination, the main nutrients in GBR, including phenolic compounds, γ-oryzanol and essential amino acids, especially γ-aminobutyric acid (GABA), increased considerably. GABA is an important and ubiquitous non-protein amino acid that is primarily produced by α-decarboxylation of L-glutamic acid and catalyzed by enzyme glutamate decarboxylase. It plays an important role as the main inhibitory neurotransmitter in the mammalian central nervous system (Kinnersley and Turano, 2000; Kanbara et al., 2005). Many researchers reported that GABA has many health benefits, and an intake of GABA over time helps reduce sleepless depression (Okada et al., 2000), lower blood pressure (Inoue et al., 2003), and inhibit leukemia cell proliferation and stimulate cancer cell apoptosis (Oh and Oh, 2004).

It is generally recommended that the GABA content in plants is increased under stress conditions such as hypoxia, cytosolic acidification, mechanical damage, cold shock, heat shock, darkness and water stress (Shelp et al., 1999; Oh et al., 2003; Oh and Oh, 2004). Rice germ and bran is the major source for GABA accumulation. The accumulation of GABA in rice germ is mainly dependent on soaking condition, the simplest method to increase GABA contents. A high-pressure treatment by promoting the enzymatic reactions and the gaseous treatment which simulates the hypoxia condition are additionally recommended after soaking to enhance the GABA accumulation in rice germ (Sasagawa et al., 2006; Komatsuzaki et al., 2007). For instance, GABA content of Thai aromatic brown rice (Khao Dawk Mali 105 variety) increases about 11-fold from 2.10 to 23.31 mg/100 g rice after germination (soaking with water at 35 °C for 4 hours and then incubating at 35 °C for 20 hours) (Cheevitsopon and Noomhorm, 2011).

11.2 Drying of food grains

Heating, such as drying, is one of the most energy consuming processes in grain processing. Significant amounts of energy are used in the conventional methods for drying wet materials such as biomass (e.g. grains), because the latent heat for evaporating water is large. There is no disagreement among researchers that drying is a key area where energy savings need to be addressed. It has been reported that drying accounts for at least 15% of industrial energy consumption (Kemp, 2005).

Among several drying techniques commonly used in drying particulate materials, fluidized bed drying has caught some attention due to its potential advantage over fixed bed drying (Mujumdar, 2004). Moreover, due to the rapid drying it has been considered as an economical drying method compared with other drying techniques. Lower shrinkage has been experienced in fluidized bed drying compared to fixed bed drying probably due to case

hardening at high temperature and changes in visco-elastic properties occurring during drying.

Considerable work has been done in various aspects of the development of fluidized bed dryers which is reviewed in this chapter. However, there have also been several novel approaches to dry paddy to reasonably safe storage levels right after harvesting at farms. This has been necessitated due to poor infrastructure of transportation and storage facilities. The purpose of such small scale dryers is to boost profit margins for farmers by removing moisture up to 2–4%.

Jindal and Oblado (1986) and Puechkamutr (1988) worked on accelerated drying of high moisture paddy using conduction heating for a rotary dryer. Their studies have shown the potential of using high temperature for quick drying of paddy without significant damage to the grain. This technique has been reported to be promising from an energy consumption point of view. Puechkamutr (1985) developed a rotary dryer for the paddy based on conduction and natural convection heating. Paddy was effectively dried from moisture content of 23 to 16% (wb) using a pipe heat exchanger at surface temperatures of 170 to 200 °C with a residence time of 30 to 70 seconds. Rapid drying and good milling quality of the paddy could be achieved with such a dryer.

11.2.1 Combined conduction-convection heating rotary dryer

The combination of a conduction and convection heating type rotary dryer was developed for on-farm drying as a first stage drying. It consisted of double cylinders: the external cylinder with 500 mm diameter, attached to the inner surface with straight flight; and an inner hexagonal cylinder, with an outer tray and firing device installed inside as a part of inlet cylinder. The grain was cascaded inside the external cylinder with a concurrent flow of air. The experimental results showed the reduction of 3% of moisture content with a single pass with negligible reduction in milling quality (Likitrattanaporn, 1996).

Another study of combined conduction-convection type rotary drum dryer was reported by Regalado and Madamba (1997) in terms of thermal efficiency. The fresh ambient air forced inside the drum in a counter flow direction of grain brought evaporative cooling of the hot grain as shown by the increase in moisture reduction whenever air velocity was increased. In another study, Likitrattanaporn et al. (2003) designed a combined conduction and convection heating rotary dryer for 0.5 ton-hr^{-1} capacity using LPG as the heat source, in order to dry high moisture paddy at farm conditions. The main aim was to find out an affordable way to dry field paddy on the day of harvesting to facilitate handling and for higher returns of the produce for the farmer. The emphasis

was placed on finding out the operating conditions in which moisture up to 3% can be removed in a short time while grain quality should be close to fresh paddy. Performance of the rotary dryer in terms of moisture removal, residence time, energy consumption and milling quality were evaluated.

A further improved prototype of combined conduction-convection type rotary drum dryer was the provision of ambient air which was forced inside the drum in counter-flow to the direction of the cascading grains. The grain was heated by conduction heating as drying proceeded and followed by convection heating as cooling of the heated grain occurred. The results showed that its partial drying capacity approximately doubled that of the pre-dryer developed by IRRI, requiring only single pass operation. Neither drum surface temperature nor ambient air velocity and their interaction influenced total milling recovery and head rice recovery.

This experimental rotary dryer designed with a con-current flow system comprised of two primary parts; a double cylinder and a discharge cover. Forward movement of paddy takes place by inclination angle and rotary motion of cylinder, while air is blown through the cylinder by the suction fan located on top of the discharge cover. One horse power (hp) motor with 1:60 reduction gear was used for driving the rotary dryer. The LPG lamp on the entry end heats up the air and heated air moves to the other end due to suction fan. During forward motion, the paddy first contacts the outer surface of the inner cylinder where conduction heating takes place followed by a cascading action along the inside of the external cylinder resulting in convection heating.

Relatively less moisture was removed during the last (3rd) pass at temperatures of 100 and 110 °C i.e., 1.5 and 1.7%, respectively. Then at 120 °C 2.1% of the moisture content could be removed. It is due to the reduced availability of free water at the 3rd pass of drying.

The conduction and convection zones are clearly mentioned along with the inlet and outlet temperatures of grain and the hot air. It can be seen that high temperature in the conduction zone can remove a greater amount of water than the convection zone which is, in turn, sucked out by the hot moist air. The outlet grain temperature dropped to the safe range (max. 52 °C) within a very short time (2–3 min).This demonstrates the dryer's heat exchange efficiency. The comparison of the effects of conduction heating and convection heating on moisture removal showed that the major moisture content of paddy was removed by the conduction heating for all temperatures while the convection heating could remove less than 0.4% of moisture. Designed as the mobile unit for drying paddy in the field, energy consumption is one of the most important aspects to consider. The difference in weight before and after running a pass was recorded.

Statistically insignificant difference was found in the weight of LPG consumed at all temperatures. The average power consumption was, however, 0.6 KWh and produced power of 0.46 kg/hr LPG. It was estimated that the operating cost to remove up to 1% of moisture content of one ton paddy was

US$ 0.23$ in the first pass. The cost increases up to US$ 0.33 in the second pass and subsequently increases in the 3rd pass depending on the availability of free moisture.

11.2.2 Fluidized bed dryers

The fluidized bed grain dryer has obtained significant commercial interest in recent years. Its potential is great especially for high moisture grains such as paddy, parboiled rice, maize and soybean. Its drying rate is much faster when compared to the conventional grain dryers. Consequently, the size of the drying unit is very compact relative to its capacity. Its energy consumption is relatively low without any detrimental effects on grain quality. A comprehensive review of fluidized bed dryers has recently been reported by Soponronnarit (2003) with the emphasis on the research and development efforts on fluidized bed grain drying, starting with an experimental batch dryer and culminating with a commercial continuous-flow dryer.

The fluidized bed paddy dryer is competitive with conventional hot air dryers especially at high moisture level, that is, low energy consumption, low cost and acceptable paddy quality. Important operating parameters are: drying air temperature of 140–150 °C, fraction of air recycled of 0.8, air velocity around 2.0–2.3 m/s and bed thickness of 10–15 cm. Under proper conditions such as high initial moisture content of paddy (higher than 30%) and high air temperature (140–150 °C), head yield can be increased up to 50% compared to ambient air drying. For consumer acceptance, tested rice with fluidized bed drying is not significantly different from that dried by ambient air. For other grains, the fluidized bed dryer has great potential for commercialization. Many units have been used in parboiled rice mills, a few for maize and soybean industries. Experimental results obtained from commercial fluidized bed dryers show good performance and good product quality with a significant spin-off that urease activity in soybean kernel could be reduced to an acceptable level required by the animal feed industry.

Regardless of the drying method, several strategies can be used to reduce the moisture of grains with less energy consumption, some of which are mentioned below.

Pinch Technology provides a new approach to process integration based on the application of the Pinch Principle. The pinch technology not only addresses energy savings but opens up opportunities for the new techniques which include retrofit design procedures, evaluation of capital-energy trade-offs, appropriate integration of cogeneration schemes and design methods for improving flexibility.

The principle of pinch analysis comprises of hot and cold streams: heat can be recovered between hot streams at a higher temperature and cold streams at a lower temperature. However, processes have a pinch temperature above which there is a net heat requirement; whereas there is net waste heat rejection

below the pinch. Heating below the pinch, cooling above the pinch or heat exchange across the pinch all incur an energy penalty. Conversely, heat pumps only achieve a real energy saving if they work backwards across the pinch, upgrading useless below-pinch waste heat to useful above-pinch heat. Hence, a pinch analysis of a system is an important prerequisite of any energy saving project, to ensure that it achieves its aims. This technology has been implemented into driers. However, it is to be noted that pinch technology requires a systematic analysis of the overall plant and process integration.

The pinch analysis generally comprises the following sequences of steps: data extraction; construct composite curves; set energy targets; locate the pinch; identify process modifications. Kemp (2005) has comprehensively reported reducing dryer energy use by process integration and pinch analysis.

Fushimi et al. (2011) proposed an innovative drying process, based on self-heat recuperation technology that recovers not only latent heat but also sensible heat, was developed to save drying energy. Water contained in a wet sample is heated to its boiling point, and the resulting steam is superheated. The superheated steam is compressed to provide a temperature difference for heat exchange.

The condensation heat of the compressed steam is exchanged with the evaporation heat of the water from the wet sample. The sensible heat of the compressed steam is utilized to raise the temperature of both evaporated steam (superheating) and water contained in the wet sample (preheating). In addition, the sensible heat of the dried sample is recovered by gas to improve the overall energy efficiency. This proposed drying process based on self-heat recuperation was found to drastically reduce the energy consumption to 13.7% of the energy consumption of the conventional drying process with heat recovery.

An energy-efficient adsorption dryer design that considers sensible and latent heat recovery as an integral part of drying system design developed by Atuonwu et al. (2011). Operating conditions for optimal energy performance were evaluated by pinch-based optimization subject to product quality. Results for a single-stage zeolite adsorption drying process with simultaneous heat recovery optimization show a 15% improvement inefficiency compared to a sequentially optimized system. The improvement is traceable to alterations in enthalpy-related variables like temperatures and flow rates. The discrepancy in optimal operating conditions between the sequential and simultaneous cases underscores the need to change system operating conditions when retrofitting for heat recovery because previous optimal conditions become suboptimal when heat recovery is introduced. Also, compared to a conventional dryer (without an adsorption process) operating under similar conditions, energy consumption is reduced by about 55%.

Assessment of the various approaches to sustainable drying process has been reported by a number of authors, for example, Baker (2005) has reviewed energy consumption in drying, including fluidized-bed drying. Baker and Al-Adwani (2007) evaluated factors influencing the energy-efficient

operation of well-mixed fluidized bed dryers. Baker and McKenzie (2005) studied the energy consumption of industrial spray dryers. More recently, Johnson and Langrish (2011) compared various methodologies, as applied to spray drying, to develop an objective methodology to optimize the quality of energy used, as well as the quantity, while integrating different forms of energy into the analysis to allow for a simple comparison on the basis of cost and environmental impacts.

11.3 Pre-storage grain treatments

Both pre- and post-processing storage of grains make them vulnerable to damage due to infestation by insects and/or microorganisms. In general, synthetic chemicals such as insecticides, antibacterials, antifungals and so on are used as protectants to protect against such damage. However, these types of synthetic chemicals are often considered harmful for individual's health and the environment. Therefore, use of such chemicals for protecting grain damage (in both pre- and postharvest) should be limited and finding the suitable alternatives to the chemicals is a must.

In Southeast Asia, postharvest losses are around 10–37%, out of which 2–6% losses occur during rice and other grains storage have mainly been reported due to insects. In the case of Thailand, usually a small scale rice mill has the open structured storehouses with poor sanitation and an incorrect method of storing rice. Thus maize weevil (*Sitophiluszeamais*), which is the predominant insect in a rice mill, can contaminate milled rice during storage. When infested rice was packed in PE plastic bags, the insect emerges and causes severe damage to packaged rice. According to Sirisoontaralak and Noomhorm (2005), suitability of various methods; gamma irradiation, packing under reduced oxygen and enriched carbon dioxide and combination of the two techniques, to control infestation of maize weevils in packaged rice was investigated as alternatives to traditional fumigation. The optimum treatments to control insects in packaged rice are based on the effects on insect mortality, milled rice quality and the storability of packaged rice (Table 11.3). This study recommended irradiation at 0.2 kGy, packing under vacuum and packing with carbon dioxide concentration of 30 and 40% to be the alternatives to phosphine fumigation.

Alternatively, natural product treatments are also generated for grain protection and as sustainable alternatives to synthetic insecticides in the control of the maize weevil. Ogendo et al. (2004) investigated the effect of insecticidal plant materials, *Lantana camera* L. and *Tephrosiavogelii* Hook, on the quality parameters of stored maize grains. The plant powders could reduce insect damage by 25% and had no effect on the germination of maize grains. Therefore, the use of plant powders is found to be cost-effective and a sustainable alternative to synthetic insecticides in maize grain storage. The trends in insect control operations with emphasis on sustainability are given below.

Table 11.3 Effects of the proposed techniques on insect mortality, milled rice quality and the storability of packaged rice

Treatments	Doses	Insect mortality	Changes of milled rice quality during storage*	Estimated shelf life** (months)
None	F0	Not complete	Higher TBA peak Lower SB, CS, FV	4
Fumigation	F1	Complete	-	13–16
	F2	Complete		
	F3	Complete		
Irradiation	Ir0.2	Complete	Higher b value Higher TBA peak Less increase in HN Lower BD, SB	9
	Ir0.5	Complete		7
	Ir1.0	Complete		2
Packaging	AP	Not complete	Lower b value	19–28
	Vac	Complete	Lower TBA peak	
	C20	Not complete		
	C30	Complete		
	C40	Complete		

*Changes were compared to quality of fumigated rice packed in PE, which represented the changes of quality solely from ageing effects

**Estimate from linear regression of overall acceptability score and storage time with score at '5' as a criterion.

11.3.1 Chemical fumigation

Bags of milled rice are stacked and covered with gas proof sheets to which fumigants are then added to allow elimination of insects. The most frequently used fumigants are phosphine and methyl bromide. Chemical fumigation has an uncertain future due to its limitations in terms of insect resistance, toxicological findings and consumer concerns on health and environment (Banks, 1987). Methyl bromide was phased out by 2001. Phosphine has not been a preferred medium for millers due to long fumigation requirements. It takes a minimum of seven days to be effective against all stages of all stored product pests by phosphine fumigation at more than 25 °C (Winks et al., 1980). Susceptibility to phosphine varies by life stages and insect species. Phosphine efficiency in killing insects depends more on its exposure time than the phosphine concentrations (Soekarma, 1985). ACIAR (1989) recommended an application dosage rate for phosphine at 1.5 (g/m^3) or 2 g/tonne rice with minimum exposure periods of seven days (above 25 °C) and 10 days (15–25 °C) to obtain a complete destruction of insects.

Fumigants can have unwanted and adverse effects on treated commodities in terms of germination, taste, odour, appearance, texture of grains, processing parameters, mold growth and mycotoxin formation (ACIAR, 1989).

Response to fumigants may be dependent on the types and varieties of commodity, water activity, temperature, gas concentration and the exposure time.

11.3.2 Heat treatment

A heat disinfestation system can be designed and developed with the balance among heat doses, insect mortality and deterioration of grain quality. Many types of heat sources were introduced to destroy the insects. Hot air convection heating using a fluidized bed dryer was applied to disinfest wheat. Exposure times of 12, 6 and 4 min at the air temperatures of 60, 70 and 80 °C respectively was sufficient to induce complete disinfestations. Using a spouted bed dryer, an increase in air temperature from 80 to 100 °C decreased the exposure time required to obtain a given mortality of *R. dominica* (Beckett and Morton, 2003). Many published works presented successful use of radiant heating such as infrared, microwave and dielectric heating to disinfest stored grain and cereal products (Boulanger et al., 1971). However their use might be limited as above a certain applied dose induced an increase in temperature to a level that deteriorated the grain quality and nutritional value.

11.3.3 Gamma irradiation

Gamma irradiation is an effective alternative technology because of its ability to kill and sterilize insects in infested rice grains. The successful application of irradiation to control stored product insects has been reported (Aldryhim and Adam, 1999). Doses of 0.1 to 5 kGy may give complete destruction within a few hours to weeks. Although immediate kills are required to reduce the grain loss, use of irradiation is limited by its effect on grain quality. Consumer acceptance is very important and optimum doses should be determined. Various doses have been reported to maintain sensory quality of irradiated rice. An acceptable limit below 3.0 kGy was recommended for Taiwanese rice and up to 5 kGy for Indian rice (Roy et al., 1991). Bao et al. (2001) also concluded that irradiation of milled rice for human consumption would be limited to a maximum dose of 2 to 4 kGy because of its negative effect on rice colour and aroma. However, less than 1 kGy was suggested for Australian rice and ordinary Thai rice (Wootton et al., 1988).

Aromatic rice is an important export commodity for Asian countries. Economically, it occupies a special position in the international market due to its pronounced, pleasant and fragrant odour and satisfying soft texture after cooking. Sirisoontaralak and Noomhorm (2005) reported changes of physicochemical properties of packaged aromatic rice (KDML-105) when using gamma irradiation at dosages of 0.2 to 2.0 kGy. Beside an increase in lipid oxidation (TBA numbers) after irradiation, volatile compounds

(ACPY, 2-acetyl-1-pyrroline) decreased. These affected sensory perception. Maximum doses of less than 1.0 kGy should be used to disinfest aromatic rice although when considered strictly on aroma, less than 0.5 kGy would be more suitable.

11.3.4 High pressure processing (HPP)

High pressure (HP) technology has been recognized as useful in the food industry. The effects of high pressure are instantaneous throughout a food product and are independent of product composition, size, mass, or geometry. The absence of transport limitations gives high pressure processing a unique advantage over all other processing methods. The effect of a high pressure treatment is influenced by various intrinsic and extrinsic factors. Treatment time, pressurization/decompression rate, temperature and the number of pulses are critical to the effectiveness of the process (Knorr, 2001). The effect of temperature and high pressure (HP) pretreatment on hydration behaviour of KDML 105 has been reported by a number of researchers. (Baka, 2007). Changes occurring in length, width and water absorption were determined. Studies on eating quality of cooked rice and quick cooking rice and pasting properties of rice flour that is treated by HP showed that length, width and rate of water absorption of rice grains were positively correlated with all three parameters (pressure, temperature and time). Therefore, the application of a combination of HP and temperature has the potential to shorten the soaking time necessary to reach the required moisture content. The eating quality of treated cooked rice was compared with untreated cooked rice with respect to cooking time, hardness, stickiness, elongation ratio, volume expansion ratio and colour. The cooking time of KDML 105 was 18 minutes while soaking of rice grains by combination of HP and temperature reduced the cooking time of unsoaked rice grains to 9, 7 and 3 minutes for 25 °C, 55 °C and 70 °C, respectively. The hardness of treated cooked rice was significantly lower and exhibited higher stickiness than untreated cooked rice. Hence, it is possible to change the properties of aged rice with this process to obtain new rice. The elongation ratio of treated cooked rice was not significantly affected by temperature and pressure as compared with untreated cooked rice whereas it was slightly affected in volume expansion ratio by pressure 100–300 MPa due to the structure of rice grain which, when pretreated by HP, seemed to promote the water penetration and brought about a higher degree of swelling in rice grain. The degrees of yellowness of treated cooked rice were lower significantly than untreated cooked rice but were nearly the same in degrees of brightness. These phenomena are also found in eating properties of quick cooking rice with pretreatment by HP. From the above, it was concluded that the treatment with HP would be effective in improving the cooking properties of rice grains. HP treatment also affected pasting properties of rice flour. Treated rice flour increased in peak viscosity and breakdown whereas a

decrease in final viscosity, pasting temperature, peak time and setback implied that HP-treatment can improve palatability and retrogradation of cooked rice.

11.3.5 Modified atmosphere

Modified atmosphere involves alteration of the concentration of the normal atmospheric air, which contains about 21% oxygen and 0.03% carbon dioxide, present in storage which has the effect of an insecticide and prevents deterioration of quality. Reduction of oxygen concentration or increasing the carbon dioxide concentration are the two different ways to modify the atmosphere in packaging.

a. *Low oxygen atmosphere*
Low oxygen atmosphere can be obtained by storing grain in sealed enclosures or in airtight storage and allowing the natural biological process from infested insects and grain, called hermetic storage, to occur. Insects of various species were killed by depletion of oxygen rather than accumulation of carbon dioxide. Adults were more resistant than immature insects. A lethal oxygen level for all life stages of insects at <3% was obtained depending on the density of insect population (Moreno-Martinez et al., 2000) and the rate of oxygen re-entry into storage containers. Beside of hermetic storage, oxygen is generally reduced by removing air from storage containers to create a vacuum condition of which lower pressure than atmospheric pressure was shown. Exposure time required to kill insects using low pressure condition varied from insect species, insect life stages and the pressure level. When pressure below 100 mm Hg was applied, exposure time ranged from 7 to 120 h (Finkelman et al., 2003; Finkelman et al., 2004). Eggs seemed to be more tolerant than pupae and adults. Immature stages of some insects developing within the grain kernel were more resistant than those outside the kernel. *Saccharomyces oryzae* was considered to be more resistant than other insect species. When using higher pressure above 100 mm Hg insects had a shortened life and ovi position was reduced. With the advent of modern plastic materials, airtight laminated food pouches made from low gas permeability plastic films were introduced to control insects by restricting oxygen and carbon dioxide transfer and creating an atmosphere lethal to insect survival. Vacuum packaging was also efficiently proved to control insects during storage of milled rice (Kongseree et al., 1985).

b. *High carbon dioxide*
Carbon dioxide has some level of toxicity to insects, but it generally deprives the insects of oxygen and kills by suffocation. The depletion of oxygen was the factor more important than the increase in carbon dioxide when controlling insect populations. However, when carbon dioxide was present oxygen was used up more quickly and adult insects died at relative higher concentrations.

Exposure time needed to kill insects under high carbon dioxide atmosphere depended on insect species, life stage and carbon dioxide concentration. Most of the stored product insects are killed under an atmosphere of <3% O_2 or >40% CO_2.To obtain complete destruction of insects, carbon dioxide fumigation for several days was required for different species of insects at different growth stages. Annis (1987) identified that *Sitophilusoryzae* (rice weevil) was amongst the most tolerant stored product insect to carbon dioxide rich atmosphere. Proposed exposure time to *S. oryzae* when using >40% carbon dioxide at 25 °C was 15 days, which therefore was adequate for all other species. Even at a potent carbon dioxide concentration of 95%, a long exposure time was required to kill all developmental stages of *S. oryzae* showing LT_{99} at 1.26 to 15 days (Annis and Morton, 1997). Comparing weevil types, *S. oryzae* was more tolerant to carbon dioxide than granary weevil *S. granarius*. For different insect species, adults of *Triboliumcastaneum* (Herbst) seemed to be more tolerant than *S. oryzae*at at carbon dioxide of 45–80%.

c. *Modified atmosphere at increased temperature*
Increasing the temperature resulted in increased insect mortality when insects were exposed under high carbon dioxide. Combination of temperatures >38 °C with carbon dioxide enriched or oxygen deficient atmospheres increased mortality of *T. castaneum* (Herbst) larvae (Soderstrom et al., 1992). It was confirmed when using a combination of low oxygen concentration and increased temperature (26–35 °C) (Donahaye et al., 1996). Higher temperatures (20–40 °C) also gave a shorter exposure time needed to obtain mortality of all live stages of the many stored product insects in packaged rice under reduced pressure (Locatelli and Daolio, 1993).

11.3.6 Pressurized carbon dioxide

Under high carbon dioxide atmosphere, even at high concentration, exposure time to obtain a complete mortality of insects was compared to chemical fumigation. This limits its use. To reduce exposure time, there was a successful test conducted by Nakakita and Kawashima (1994); who introduced the use of carbon dioxide under pressure (5–30 bars) followed by sudden loss of pressure. With carbon dioxide at 20 bar, an exposure time of 5 minutes was sufficient to kill all adults of *S. zeamais*, *R. dominica*, *T. castaneum* and *L. serricorne*. But eggs of *S. zeamais* required treatment at 30 bars for 5 minutes for complete kill. In contrast, the application of helium had no effect on adult mortality even at 70 bars.

From a commercial point of view, application of carbon dioxide gas at a higher level is restricted with costly equipment and difficulties in controllability. Noomhorm et al. (2005) suggested the application of pressurized carbon dioxide at a lower level (4–8 bars) to kill *S. zeamais* in milled rice using a specially designed pressure chamber. Carbon dioxide at a pressure of 4, 6 and

8 bars were found to shorten the exposure time to obtain a complete destruction of *S. zeamais* adults from 21 hours at atmospheric pressure to 6, 2 and 2 hours respectively. A few survivors of immature insects were observed when exposed for 5 hours at 6 and 8 bars. The adult stage was the most susceptible stage while larvae and pupae were relatively more tolerant. After the pressurized treatments milled rice qualities in terms of cooked rice hardness and pasting properties slightly changed, however, panelists could not observe the difference of non-treated and treated rice when sensory qualities were evaluated.

11.4 Post-harvest value addition

11.4.1 Co-products utilization

During grain processing, many variable co-products are created. The most basic types of co-products from grain processing are husk or hull and bran. In particular, for oilseed and ethanol processing, the important co-product is oilseed meal or distillers grains. Conventionally, grain husk is used as stove fuel and the others have been used for feeding animals. For the sustainable aspect, utilization of the co-products is not only helpful to solve pollution problems due to fermented wastes and the particulates in atmosphere after burning but also to develop new, environmentally friendly products.

Grain husk is now becoming a potential alternative for wood and can be used as a composite material for packaging, construction, and so on. The study of Bledzki et al. (2011) shows that wheat husk and rice husk had the potential to be used as reinforcements for thermoplastics as an alternative to or in combination with wood fibres. Wheat husk composites showed 75% whereas rice husk composites showed 23% better elongation at break than soft wood composites. Rice husk composites also showed positive results. Due to a coupling agent (maleic anhydride-polypropylene copolymer with an acid number of 37–43 mg KOH/g), tensile strength of composites improved 25% for soft wood, 35% for wheat husk and 45% for rice husk.

However, a major challenge of grain husk utilization is to use it as a substitute for fossil-based raw materials. Grain husk is a ligno-cellulosic material. It is renewable and available in abundant volume. However, the sustainable use of grain husk is to produce bio-fuel. As reviewed by Silva Lora et al. (2011); the apparent rationale for using the terms ‘sustainable’ in the context of bio-fuels are the following: first, bio-fuel production from biomass is largely carbon neutral (that is, the CO_2 produced as the fuel is combusted, is offset by the carbon absorbed as the biomass is grown). Second, bioconversion processes in general do not produce hazardous compounds. Third, biomass production and microbial conversion processes can be developed and used in a more distributed manner, avoiding the need for long distance transport of fuels.

Preliminary combustion studies of rice husk in a pot furnace indicated an optimum rate of combustion to be 70 kg husk/m^2hr with 60% excess air. The following considerations were incorporated in designing a husk-fired furnace:

1. Setting up a mixing chamber adjoining the furnace, in which the products of combustion with ambient air should take place in order to attain the necessary temperature from the gas-air mixture stopping the flying ash and sparks from going into the drying chamber.
2. An arrangement permitting the rapid change in the direction of the flue gases either to the chimney or to the drying chamber.
3. The furnace should ensure the best combustion of the fuel, as the appearance of smoke or soot in the products of combustion may cause not only the lowering of efficiency of the furnace but also deterioration in the quality of dried grain.
4. Convenience and simplicity of maintenance should be taken into account.
5. It should preferably be a portable unit.

Rice husk can be used as a source of energy in a box type furnace for supplying 1680 cubic meters per hr (1000 cfm) at 700 °C to 1200 °C. The furnace is equipped with an inclined grate (45° angle, 0.5 m^2) consisting of the cast-iron bars in a staircase fashion. At the bottom of the inclined grate is a horizontal revolving grate which disposes of the accumulated ash at certain intervals. In between the combustion space comprising the inclined and horizontal grates and the outlet for the flue gases, there is a curtain wall throughout the width of the furnace. The height of the curtain wall is a little over the outlet so that no amount of un-burnt husk or fly ash goes into the chimney. The husk is fed at the top of the inclined grates with the help of a feeding roller mounted in the hopper and powered with a 1/8 hp motor. The husk is spread in a thin layer throughout the width of the furnace and flows down the inclined grate by its own gravity while combustion takes place. The burnt husk or ash is disposed off intermittently by rotating the horizontal grate. The suction end of the blower is connected with the outlet of the furnace. A secondary inlet to the blower is made to bring in the ambient air to the mixture of the air and the flue gases at a required temperature supplied by the blower either to the drying chamber or the chimney.

With the feed rate of 11 kg-hr of husk, the supply of 1680 cubic meters per hr (1000 cfm) of heated air flue gas mixture can be maintained at 1000 °C. The furnace provides a perfect combustion with no traces of smoke in the flue gas. The flue-gas analysis shows that it comprises about 3% CO_2, 16% O_2, 81% inert nitrogen butno carbon monoxide. It should be added that the gas-air mixture is nearly as good as the heated ambient air for drying purposes and has no detrimental consequences on the dried paddy.A continuous down draft rice husk gasifier can be used as a heat source for paddy drying using a rotary dryer. Continuous down draft rice husk gasification achieved an air supply rate of

2.82 kg/hr, rice husk feed rate 6.46 kg/hr and 30–50 cm char thickness with 42.34% gasification efficiency. The operating condition of gasifier produced 39.10 MJ of heat per hour with air fuel ratio 0.038 kg/kg and specific gas production rate 195.68 $m^3/(hr \cdot m^2)$.

The output heat can be applied in the rotary dryer to create three different temperatures; 60–80, 80–100 and 100–120 °C with the optimum drying temperature of 60–80 °C. Drying of paddy with a hot air temperature between 60–80 °C had improved milling yield when compared with shade dried reference paddy. The milling yield of the shade dried was about 35% whereas the maximum yield of hot air dried sample was 44.05% after drying for 15 minutes and moisture content was 18.22% moisture content then it was tempered for 2 hours and shade dried until final moisture of about 14% moisture content. In addition, the whiteness, yellowness and white belly value of paddy dried at 60–80 was 40.73, 17.81 and 12.60, respectively. To maintain good head rice yield, it is recommended that high moisture content paddy should be dried to about 18% moisture content followed by tempering for 2 h before shade drying until final moisture is about 14%.

Thorough research on comparative life cycle assessment (LCA) of rice husk utilization in Thailand was conducted by Prasara-A (2009). Rice husk can be used as a fuel to substitute for fossil fuels and coal. It can also be used as a feedstock in the cellulosic ethanol production. E10 (10% ethanol blended with 90% petrol) of 100 litres can help to save approximately 6.6 litres of petrol. This contributes to a reduction of the impact on fossil fuel depletion, especially in the case of the nations having very limited local fossil fuels sources such as Thailand. Based on the LCA results of this research with regard to the impacts on fossil fuel depletion and climate change (CO_2 emission), the use of rice husk as a fuel in electricity production is the most practical environmentally friendly for Thailand as compared with using as a fuel to substitute for coal in the cement production and as a feedstock in the cellulosic ethanol production. The electricity production option can help to save the largest amount of the energy required for future extraction of the fossil fuels used rather than the other rice husk use options. In addition, this research also suggested using rice husk ash produced from the rice husk power plants for lightweight concrete block production. It can be used to substitute for 40% of Portland cement. This application caused less impact on climate change, terrestrial acidification, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, freshwater ecotoxicity, marine ecotoxicity and fossil fuel depletion, while the worst case was the application for landfill.

Apart from utilization of rice husk as a fuel, rice husk is useful as an organic fertilizer (Ebaid and El-Refaee, 2007). Xylose, activated carbon and silica can also be prepared from rice husk (Lima et al., 2011). Silicon content on rice husk surface is 10.8% (Bledzki et al., 2011). Rice husk ash is now used in the preparation of novel adsorbents as a measure of environmental pollution control (Foo and Hameed, 2009).

In the grain-based ethanol industry, fermentation produces a co-product known as distillers dried grains with solubles (DDGS). DDGS is conventionally used as an ingredient for livestock feeds. In fact, this co-product contains many nutrients such as linoleic acid, dietary fibre such as β-glucan and antioxidants (e.g. vitamin E) which provide many health benefits (Gibreel et al., 2011). To improve economic sustainability of the ethanol industry, the important nutrients should be maintained in DDGS. Liu (2008) found that there is highly heterogeneous distribution of nutrients in sized fractions of DDGS and it is highly feasible to fractionate DDGS for compositional enrichment based on particle size.

The brewer's spent grains (BSG) are still underexploited in most of the developing nations. BSG is the main by-product of the brewing industry, representing approximately 85% of the total by-products generated, is rich in cellulosic and non-cellulosic polysaccharides and has strong recycling potential. Spent grains are the by-products of the mashing process, which is one of the initial operations in a brewery in order to solubilize the malt and cereal grains to ensure adequate extraction of the wort (Fillaudeau et al., 2006). BSG has generally been sold for animal feed production, production of value-added compounds (e.g. xylitol, lactate), media for microorganisms or as raw materials for the extraction of compounds such as sugars, proteins, acids and antioxidants.

BSG has historically been used in animal feed industries (Szponar et al., 2003); it has the right amount of cellulose, hemi-cellulose, lignin and a substantial amount of polysaccharides and proteins. The higher moisture content (about 80–85%) together with an abundant amount of sugars and amino acids make it vulnerable to spoiling and having a short shelf life (7 to 10 days). The incorporation of BSG in non-ruminant diets has been found to be beneficial for intestinal digestion, alleviating both constipation and diarrhorea; this may be due to the higher content of glutamine-rich protein, and the high content of non-cellulosic polysaccharides and smaller amounts of β-glucans (Tang et al., 2009).

BSG has many components (e.g. fibre, protein, minerals, vitamins etc.) which make it of potential value as a food ingredient as well. BSG has also been used as a substrate for the production of lactic acid, using strains of *Lactobacillus* (Shindo and Tachibana, 2004). The lactic acid is now aiming to manufacture biodegradable polymers. A few of the following subjects are under investigation for the application of BSG in sustainable use of grains in the brewery industry:

i. Use as soil conditioner/organic fertilizer.
ii. Pyrolysed BSG can be used as an adsorbent for volatile organic chemicals.
iii. BSG washed with sodium hydroxide has found enhancing metal ion adsorption characteristics.

iv. Could be used as a cheap adsorbent material for removal of dye from the wastewater and/or cleaner production in many food and pharmaceutical industries effluents.
v. Has been used in brick-making as sawdust composite to increase the brick porosity.
vi. Raw material for paper manufacture.
vii. Anaerobic digestion of BSG could produce biogas.
viii. Can be used as source of sugars to produce bio-ethanol.
ix. Can be used as substrate for the microorganisms to produce enzyme.

11.5 Traceability system and sustainability

In the grain supply chain system, traceability has been increasingly implemented as it is a tool to ensure a sustainable handling approach. In a nut shell, a traceability system ensures the ability to trace product routings and secure efficient recall procedures and it can also help producers and distributors to minimize damage.

With specific reference to the food sector, RFID is a very promising system because it also results in: improved management of perishable items (the continuous monitoring of item routing reduces waste and improves customer service levels); improved tracking and tracing of quality problems (in using individual product codes, RFID systems are providing a means to identify and find only defective products, and so react to any quality problem) and improved management of product recalls.

Work conducted at the Asian Institute of Technology (Thailand) demonstrated the implementation of the RFID traceability system in two distinct rice supply chain systems which demonstrated tracing source of paddy, inputs and routing system that would help miller and distributor to minimize the loss. RFID tags were embedded on a jumbo bag or container for rice to be exported and on a plastic bag for the domestic market. The data collected from farm to rice mill were based on GAP and GMP protocols for traceability system. The rice mill could implement segregation and documentation systems that trace information back to a group of producers or production region. It is now possible to apply the RFID technique to automatic inventory control and business management.

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12 Sustainable Brewing

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12.1 Introduction

Current and future developments in national and world economies are closely interconnected to sustainable, efficient and safe usage of raw materials and energy; also involved are cleaner production concepts and approaches that are ecologically, environmentally and economically appropriate for the short and long-term future of society. From an ecological and environment point of view, significant reduction of waste represents the solution to pollution problems that threaten ecosystems.

Sustainability in industrial production can be obtained primarily by improving product and process management approaches. Product management would involve maximal utilization of raw materials, reuse of by-products, recycling, as well as reduction of waste generation and/or safe disposal of wastes without affecting the environment. Attaining sustainability at a process level would involve process intensification, process integration, development and incorporation of efficient processes (process innovation). In addition, breweries can improve their sustainable performance by monitoring individual environmental, societal and economic indicators, and the composite index of sustainable development. A discussion of said approaches for brewing industries forms the underpinning theme of this chapter.

Brewing can be defined as a process involving infusion, boiling and fermentation, as beer from malt and other materials, or by infusion, mixing or boiling, without fermentation, as for coffee. In light of the above definitions, the

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following sections focus on practices and processes for sustainable coffee and beer production, and processing.

12.2 Sustainable coffee brewing

'Coffee' is the designation of the drink prepared by extraction, in boiling water, of the soluble material from roasted coffee grounds. Behind every cup of extract of arabica and robusta which is full of flavour and aroma, lies an enormous amount of effort from a number of farmers. According to the UN conference in 1987, sustainable developments are those that 'meet present needs without compromising the ability of future generations to meet their needs (Sustainability, 1999)'. Hence sustainability of coffee brewing means the way to support and secure the coffee supply chain from crop to cup without compromising the ability to do so in the future. However, when we look into the price and profit of coffee over several years, there is an increase in price; but this has not been reflected in the profit for primary producers.

12.2.1 Coffee production

Coffee is the second largest traded commodity in the world after petroleum, and therefore the coffee industry is responsible for the generation of a large amount of residues (Nabais et al., 2008). Based on USDA data (USDA, 2011), global coffee production during 2010/2011 is estimated to be over 8.2 million tons. Industrial processing of coffee fruit is done to isolate coffee powder by removing shell and mucilaginous part from cherries. In general there are two ways one can make instant coffee powder, namely the wet processing and dry processing (see Figure 12.1). In wet processing the by-products are coffee pulp, mucilage and water. On the other hand, in dry processing the only by-product is coffee hulls. In addition, coffee roasting generates silverskin, which is a tegument that covers the coffee beans. Discharge of these residues into the environment poses serious environmental pollution problems. The amount of coffee husks generated during processing is equivalent to the total amount of beneficiated grains (Andrade et al., 2012). For every ton of coffee cherry, nearly 0.18 ton of coffee husk is generated (Adams and Dougan, 1981). The alternative application of these by-products includes their use as soil conditioner, mulch, animal feed, or for production of caffeine, biogas and so on. There are several opportunities for achieving sustainability in coffee production (Adams and Ghaly, 2007), examples of which include:

- strategic application of fertilizers for cleaner production;
- effective use of resources;
- utilization of by-products;
- efficient operational design;
- introduction of basic environmental management strategies.

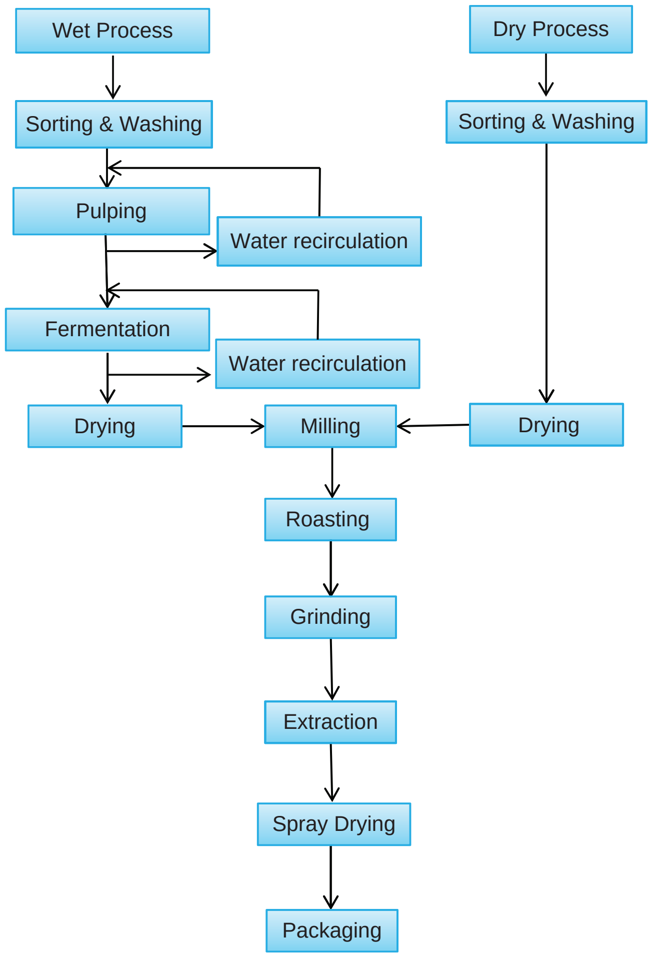

Figure 12.1 Process Flow chart of Instant Coffee Production.

At a plantation level, in spite of the relatively high use of renewable resources, the plantation phase also uses the highest quantities of resources that come from outside the system, chemical fertilizers and labour being the most important economic resources for coffee production (Giannetti et al., 2011). The assessment of *energy indices* as a function of a coffee farm's productivity in Brazil has revealed that the higher use of fertilizers increases the local productivity, jeopardizing global sustainability (Giannetti et al., 2011). Studies have revealed that the Fe and Zn contents of brown rice grains increases significantly on application of both coffee and tea waste materials during cultivation of paddy (Morikawa and Saigusa, 2011). This is due to the affinity of coffee and tea waste towards Fe and Zn.

With high coffee production projected in the upcoming years, there is an imperative need to balance this production with proper utilization and

Table 12.1 Cellular wall constituents and structural polysaccharides (%) in coffee pulp (Adopted from Braham and Bressani, 1979)

Cellular content	63.2
Neutral Detergent fiber	36.8
Acid Detergent fiber	34.5
Hemicellulose	2.3
Cellulose	17.7
Lignin	17.5
Lignified Protein	3.0
Crude Protein	10.1
Insoluble ash	0.4

industrial application of coffee by-products for development of value added products (Murthy and Madhava Naidu, 2012). Decaffeination is the process of extraction of excess caffeine, usually by supercritical fluid extraction (SFE) using CO_2 at a pressure of 4000 psi and temperature around 95 °C (Dean et al., 2000), followed by adsorption of caffeine onto activated carbon. Coffee pulp represents the most abundant waste produced during the pulping operation of the coffee cherry needed to separate the coffee grain or coffee seed. The approximate composition and amino acid profile of coffee pulp are presented in Table 12.1 and 12.2, respectively. In order to make the process clean, excess hull can be converted to activated carbon, which perhaps is the bio-char. The production of activated carbon from spent ground coffee has also been

Table 12.2 Amino acid content of coffee pulp protein compared to other important protein sources (Adopted from Braham and Bressani, 1979)

Amino Acid	Coffee Pulp	Maize	Soybean Meal
Lysine	6.8	1.7	6.3
Histidine	3.9	2.8	2.4
Arginine	4.9	3.1	7.2
Threonine	4.6	3.3	3.9
Valine	7.4	5	5.2
Isoleucine	4.2	4.3	5.4
Leucine	7.7	16.7	7.7
Tyrosine	3.6	5.0	3.2
Phenylalanine	4.9	5.7	4.9
Aspartic acid	8.7	–	–
Serine	6.3	–	–
Glutamic acid	10.8	–	–
Proline	6.1	–	–
Glycine	6.7	–	–
Alanine	5.4	–	–

successfully demonstrated and well-studied (Kante et al., 2012). Production of activated carbon involves either pyrolysis at high temperature followed by physical activation or chemical activation combined with carbonization (Clark and Lykins, 1989). The activated carbon so obtained can in turn be utilized for post-decaffeination adsorption. Recent studies have revealed the possibility for utilization of untreated coffee residues as bio-sorbents for the removal of dyes from simulated waste sludge (Kyzas et al., 2012). In some cases, solvent extraction using oil (from roasted coffee) and ethyl acetate as a solvent is employed for caffeine extraction from coffee waste. Andrade et al. (2012) evaluated several extraction techniques for extraction of polyphenols and caffeine from coffee husk and spent ground coffee. Their results highlight the potential of the SFE to increase the aggregated value from coffee industry residues. Up to 13% yield in oil extraction from spent coffee ground, at pressures of 200 bar and 300 bar and temperatures of 313.15 K and 323.15 K for 3 h of extraction has also been reported (Couto et al., 2009). Processes such as refluxed solvent extraction and supercritical oil extraction are also used for extracting oil from coffee grounds.

As shown in Table 12.2 there are various amino acids present in coffee pulp and it is compared with maize and soybean meal. In general, coffee pulp has a better amino acid profile than maize or soybean meal. It should be recalled that amino acids are the building blocks of protein and therefore coffee pulp is a significant protein source too. Another thought is that based on the composition of pulp, wherein it will be a new avenue to try out pyrolysis and gasification technology on this biomass or the pretreatment of biomass in order to know the sugar recovery for further usage (Rodriguez and Gordilo, 2011). This would help in reducing the land fill and provide scope for generation of products to fuel the energy consumed during the coffee processing itself. Mucilage is a layer approximately 0.5–2 mm thick attached strongly to coffee hulls. As shown in the composition (Table 12.3), pectin is a useful product that can be extracted from mucilage and further used in other food applications. Solid-state fermentation (SSF) is a valuable alternative for the use of coffee processing by-products as the substrate material. Recently, Machado et al. (2012) have demonstrated the ability of seven different fungal strains to grow and release phenolic compounds from coffee silverskin and spent ground coffee under solid-state cultivation

Table 12.3 Composition (%) of mucilage

Total pectin substances	35.8
Total sugars	45.8
Reducing Sugars	30.0
Non Reducing Sugars	20.0
Cellulose + ash	17.0

conditions. It is worthwhile noting that phenolic compounds have a myriad of applications in the food and pharmaceutical industries. The main residue from the processing of coffee, the coffee husk, is ordinarily used in ruminant feed. However, it is considered anti-nutritional owing to the presence of toxic substances for these animals, such as caffeine (1.2%), tannins (6.3%) and polyphenols (Andrade et al., 2012).

After the extraction of caffeine and pectin, the protein rich coffee pulp silage can be used as a good animal feed. Thus, the process can be made more sustainable instead of being discarded as a land fill. The pulp and mucilage usually discarded from the wet process can be treated with calcium carbonate and used as a fertilizer for coffee farms. This method was adopted by NESTLE in Ethiopia (Nestle, 2006) which is an economically underprivileged country but biggest exporter of coffee in the world.

In some countries, coffee silverskin separated during the roasting process has been used as soil fertilizer or as fuel. Spent coffee grounds (SCG) are the solid residues obtained during the treatment of raw coffee powder with hot water or steam to prepare instant coffee (Machado et al., 2012). Spent coffee ground is being used on a limited scale as fuel in industrial boilers of the same industry, due to its high calorific power of approximately 5000 kcal kg^{-1} (Silva et al., 1998). SCG can also serve as compost material for the production of edible mushrooms (Fan et al., 2000). Coffee waste is also a promising alternative biomass resource for bioethanol production. Bioethanol production allows reduction of CO_2 emissions and is a promising alternative to fossil fuels because it can be produced from renewable biomass. The emergence of a world market for ready-to-drink or packaged coffee drinks during the last decade further eliminates the requirements for collection and transportation of waste coffee grounds. Beverage companies produce the packaged coffee products at their relatively large production facilities and use their logistics and distribution networks to market the coffee products (Abdullah and Bulent Koc, 2013). Establishment of processing units for waste coffee ground close by main coffee processing locations would eliminate the requirement for collection and transportation of the waste materials for bio-fuel production.

As the coffee industry is expanding, the amount of water used in washing and pulping operation is also rising. In Figure 12.2, the water usage pattern in the coffee processing system using wet fermentation method is summarized. In general, the water is recycled in the operations and, in general this can be done in a day. Additionally, whenever the cleaning is done using water, high pressure spray nozzles can be employed to reduce the water consumption. The water used for washing and transportation by flotation can be recycled after having passed through a strainer. Depending on the soluble matter load, it can alternatively be sent to the wastewater treatment plant. Moreover, the composition of wastewater is rich in potassium and

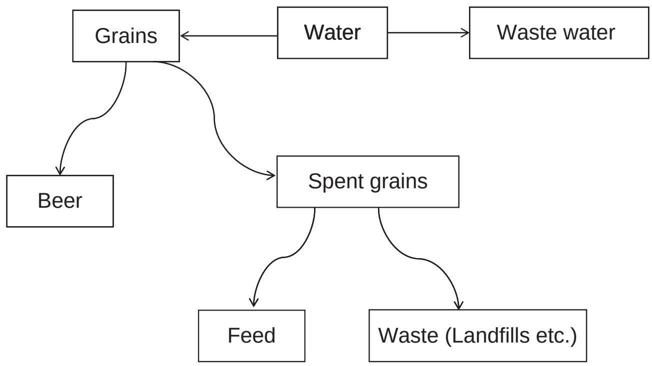

Figure 12.2 Traditional Brewing Process.

phosphorous (Hue et al., 2006). Hence, it can be redirected for irrigation purposes into the coffee plantations, following which the production cycle will be complete.

12.2.2 Energy efficient coffee processing

Coffee processing involves several pieces of equipment, at the farm and in the processing plant. At the farm level, these include weed cutters, telescopic pruner, pit diggers, power chain saw and sprayers. At the processing plant level, the equipment and machinery involved are: sorting conveyor, flotation tank, fermentation tank, pulper, destoner, dehuller, milling, size graders, spray driers and packaging machines, besides several motors and pumps. In order to make the production process more energy efficient, water recirculation, wherever possible, is a recommended option. Usage of appropriate horse power motors, instead of excess powered is yet another recommendation. Furthermore, use of pneumatic valves and pneumatic conveyors would allow consumption of less energy than if power driven. It is indispensable to train and educate the people employed in the production processes to create awareness about energy efficiency and cleaner energy. This implicitly means a reduction in the spillage loss brought about by the factory personnel. Incorporation of procedures to regularly monitor and arrest leakage can also cut down losses.

In order to achieve the target sustainability of coffee brewing, shade coffee cultivation and fair trade policy should be employed and production should be done in an organic manner. In the processing plant, water and energy usage should be minimized and the process loop should be closed wherever possible via the use of by-products. Even though it incurs some initial investment to bring about these amendments, the long-term turnover would certainly be attractive. Following the recommended guidelines would

not only improve the production efficiency and increase returns, but also allow environmental sustainability.

12.2.3 Life cycle assessment

Life cycle assessment (LCA) is a tool that can be used to evaluate the environmental load of a product, process, or activity throughout its life cycle. The environmental management practices in an Italian coffee company have been assessed by Salomone (2003), who related the main categories of environmental impact to the coffee cultivation stage. An evaluation of the environmental burdens associated with spray dried soluble coffee over its entire life cycle and its comparison with drip filter coffee and capsule espresso coffee has also been carried out (Humbert et al., 2009). It has been found that about one half of the environmental impact occurs at a life cycle stage under the control of the coffee producer, while the other half occurs at a stage controlled by the user (shopping, appliances manufacturing, use and waste disposal).

The packaging of coffee products presents considerable challenges to the food and beverage industry, and minimizing the packaging and modifying both primary and secondary food packaging presents an optimizing opportunity for the coffee industries. It does not come as a surprise that increasing recycling rates and reducing weight in the primary package are environmentally more efficient. However, this may not be completely true in the case of coffee. For example, based on life cycle assessment, it has been reported that the use of polylaminate bags instead of metallic cans in coffee packaging could be a better option in the case of small packages, even though this solution does not favour material recycling (De Monte et al., 2005). This is justified by the fact that metal transformation processes for can manufacture have high values for impacts related to heavy metals, acidification, greenhouse effect and carcinogenics.

12.3 Brewing of beer

Beer is the most popular and oldest hoppy alcoholic beverage in the world. Barley is the world's most important cereal after wheat, maize and rice, and is used mainly as an animal feed or as a raw material to produce beer (Kendal, 1994). Figure 12.3 schematically depicts the operations and resources involved in large scale brewing of beer. Brew house operations are those that are concerned with producing a fermentable extract from malt, and recovering and then stabilizing it, and encompass five processes: milling, mashing, lautering (or mash filtration), boiling and trub separation (Lewis Michael and Young, 1995; Tse et al., 2003). Thus, brewing operations in the context of beer, in a capsule, involves resources such as barley, hops, water, packaging materials, electricity, fuel, and generates a large amount of organic wastes (brewer's spent grain) and greenhouse gases (GHG).

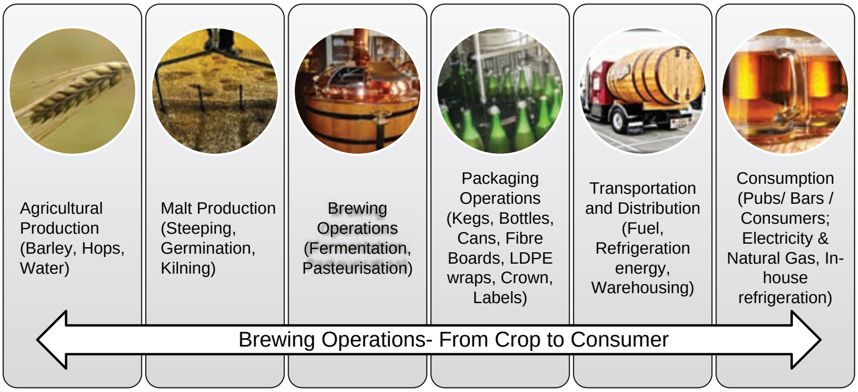

Figure 12.3 Operations and resources involved in the production of beer.

From the cultivation of the barley and hops necessary to brew the drink to the final bottling of the product, it takes an exponential amount of water to make beer. A traditional brewery that brews beer according to the German purity standards produces not only beer, but also organic waste streams and lost energy. This waste from the brewery is organic material, which means that its polluting effect could be seen as minimal. However, given the quantity of water needed for the large volumes of beer produced by today's breweries (up to more than 200 litres of water per litre of brewed beer), this organic waste is a problem (see Figure 12.2). It is also a waste considering the amount of nutrients and protein used from the grains in the beer-brewing process. A small percentage of the nutrients are used, while the protein is left untouched in the spent grains after the process. One usage for the spent grains that is occasionally explored is as an animal feed. This is not an optimal use though, as the spent grains are tough for the animals to digest. The result is indigestion and added amounts of methane gas emitted into the atmosphere by the animals.

One of the aspects of zero emissions is to increase the value added aspect of the overall process. Looking at the traditional brewery process above (Figure 12.3), the value addition generated from the waste is very low. It is actually negative if the brewery must pay for getting rid of wastewater and spent grains. In order to maximize value addition for the inputs of the brewery, the Zero Emissions Research and Initiatives (ZERI) foundation searched for the best possible ways of using the generated waste in a cascading manner (Figure 12.4). In general, spent grains are rich in fibres and protein and are an excellent substitute for flour in several high protein foods. When mixed with other fibres such as rice straw, they offer an excellent substrate for mushroom production and also biofuels production.

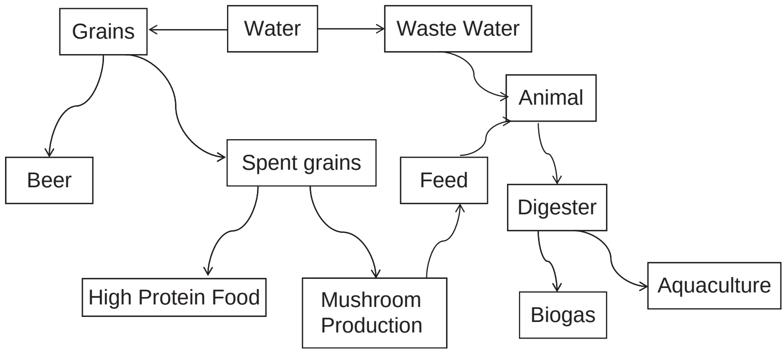

Figure 12.4 Value added brewery process.

As we know the world market for mushroom is already larger than that of coffee. The main advantage of growing mushrooms on the spent grains is that mushrooms will make the spent grains more digestible to livestock and will also increase the protein content. This may thus increase growth of animals and quality of meat.

As per recent practices, the waste from livestock is flushed into a digester with the wastewater from the brewery. These digesters generate two outputs: biogas and nutrient dense slurry. The biogas is stored in gas tanks and can be used in the brewery or sold. The nutrient rich slurry is driven into shallow basins where algae, through photosynthesis, digest it. These algae that grow and multiply on the nutrients are ideal feed for aquaculture. Moreover, the fish pond itself emulates nature with different species living at different depths. With some fish swimming from the surface to the bottom, this guarantees a healthy system functioning much like any wild lake without the need for antibiotics. By using up all the nutrients, protein and fibre from the spent grains, and the water from the process as a purification method, ZERI has set an excellent example of value addition under a cascaded scheme and thus sustainability in the brewing sector. By implementation of aforementioned concepts of integrated processing, perhaps, all breweries can completely change the concept of waste into that of a valuable resource.

Barley malt production comprises 39% of the total product carbon footprint, followed by brewery emissions (25%), glass bottle production (13%) and distribution transportation (13%) in Europe (BIER, 2012). Due to rising fuel costs and a need for the reduction of CO_2 emissions, renewable energy sources have gained growing importance in industrial energy concept planning. In the food industry, a significant percentage of raw materials leave the process as biological wastes. In a study by Sturm et al. (2012) a small scale brewery situated in north-east England was audited. Based on the data obtained, they modelled the feasibility of biogas generation. The model included a planned extension to production capacity. Several scenarios for

conversion were simulated, their gas demand determined, performance compared and economic viability calculated. The combination of either boiler or CHP with an absorption chiller were considered the most viable solutions as they create the shortest payback periods and higher additional income than the solutions without. As the former solution is more than \$320 000 cheaper than the latter and the integration in the existing system would be easier, this could be the preferable solution for a small company although this also means a reduction of additional income by roughly 30% from \$3000 to \$2000.

12.3.1 Energy efficient beer production

In the existing global scenario, adoption of sustainable development protocols is an important issue for breweries and there are numerous factors driving this concept. Larger breweries especially, focus on efficiency improvements, and have stakeholders all over the world, thus forcing them to introduce sustainability goals into their decision making (Tokos et al., 2011). Muster-Slawitsch et al. (2011) have presented a Green Brewery Concept, in which they have demonstrated the potential for reducing thermal energy consumption in breweries, to substantially lower fossil CO_2 emissions and developed an expert tool in order to provide a strategic approach to reach this reduction. Within the project of 'Green Brewery' three detailed case studies have been performed and a Green Brewery Concept has been developed. The project outcomes show that it is preferable to develop a tool instead of a simple guideline where a pathway to a CO_2 neutral thermal energy supply is shown for different circumstances. The methodology of the Green Brewery Concept includes detailed energy balancing, calculation of minimal thermal energy demand, process optimization, heat integration and finally the integration of renewable energy based on exergetic considerations.

Figure 12.5 schematically summarizes the water network and, heating and cooling systems in a typical brewery (Tokos et al., 2011). It clearly demonstrates the overall energy intensiveness of the beer brewing process. Muster-Slawitsch et al. (2011) have also shown that a brewery with optimized heat recovery can potentially supply its thermal energy demand over and above its own resources (excluding space heating). The energy produced from biogas from biogenic residues of breweries and wastewater exceeds the remaining thermal process energy demand of 37 MJ/hl produced beer. Overall, the project 'Green Brewery' has shown a saving potential of over 5000 t/y fossil CO_2 emissions from thermal energy supply for the three breweries that were closely considered.

Some of the more important engineering advances of the last 25 years in brewing and distilling are modern mash filter, wort boiling systems, cross flow or membrane filtration, yeast propagation and process improvements. Several new approaches towards reducing energy, water and effluent have

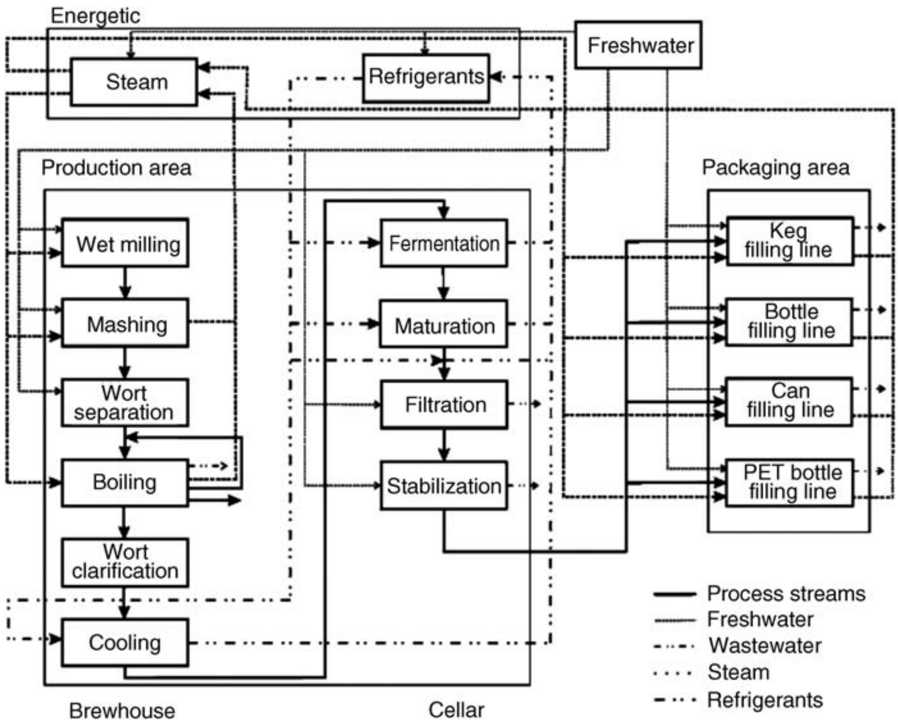

Figure 12.5 Water network, heating and cooling system in a typical brewery. Steam is used for mashing and boiling; part of the waste vapor produced during boiling is utilized for wort preheating, while the unused waste vapor is ejected to the atmosphere. Within the packaging area, the steam is used by a Clean-in-Place (CIP) system for the sterilization of filling lines and for pasteurization. Cooling is needed for the preparation of clarified wort for fermentation (chilled water), and during fermentation and maturation. (Adapted from Tokos et al. 2012, with kind permisson from Springer Science and Business Media).

been developed more recently, in addition to technologies for valorization of by-product. Within the life cycle of beer, the largest heat consumer is the brewhouse, while most electricity is used by the refrigeration system. Considering this, during the last 10 years, several new wort boiling systems have been introduced into breweries. In contrast to earlier systems, wort boiling and removal of unwanted volatiles are two separate processes in the new designs (Willaert and Baron, 2005). This innovation has brought about a considerable reduction in the thermal stress on the wort and heating costs. A wort clarification step before the stripping phase gives a better wort quality than the conventional reversed strategy where a very high thermal load was necessary during the boiling phase to avoid DMS formation during wort clarification. The removal of the unwanted volatiles can be performed at a much higher efficiency. Additionally, modern wort boiling systems are equipped with efficient energy recovery systems. Environmental aspects

include the prevention of odour pollution using vapour condensers, bio-filter treatment of recuperated vapours, re-use or membrane filtration of vapour condensate. All new systems are characterized by a considerable reduced overall energy cost compared to classical systems. Investment costs depend on the system's complexity and ease of integration into the existing process. The impact of computers, software and digital technology on process control, automation, engineering design and project implementation are reviewed (Andrews et al., 2011).

Many world leading breweries in recent times have become more energy and recycling conscious. Brewers are increasingly investing in integrated processes for steam condensation, reutilization of cooling water, usage of grey water for cleanup, collection of rainwater and harnessing solar energy to heat their kettles. However, carbon emissions also result from energy usage for retail and domestic refrigeration and not much attention has been given to this aspect.

12.3.2 Life cycle assessment

A life cycle assessment (LCA) analysis following conventional 'cradle-to-grave approach', for the life cycle of 1 L of lager beer produced by an Italian small brewery has been carried out by Cordella et al. (2007). The analysis considered the production as well as the beer consumption data. The beer consumption model included two different packaging options viz. non-returnable glass bottle and returnable keg. The needed data were mostly supplied by the brewing company and completed on the basis of literature information. Based on the analysis it has been reported that the inorganic emissions, land use and fossil fuels consumptions are the most critical environmental impacts in the beer life cycle. Barley cultivation has been identified as a very important process and it should be deepened or treated with a better precision *per se*. In general, brewing process does not appear to be a critical stage in the beer life cycle. This means that the company dimension may not be a crucial element for the overall impact quantification. With regard to the comparison between the two packaging options, beer in keg turned out to cause a lower environmental load along its life cycle than beer in the bottle due to the fact that higher emissions and higher energy consumptions were associated with the allocated glass bottles. Some results of this study are in close agreement with those reported by other researchers (Talye, 2001; Koroneos et al., 2005) who point out the relevance of bottle packaging and agriculture on the overall life cycle of beer. Based on such LCAs, it is possible to make meaningful and useful suggestions to consumers and producers for a more responsible consumption and a more environment friendly production; for example, promotion of draught beer and reusable packaging respectively (Cordella et al., 2007).

12.4 Future opportunities

Some of the challenges and opportunities in sustainability measurements are data collection, which may be simple but will be difficult to interpret. For example, climate will affect energy and water usage and hazards. These factors are interlinked. The other major obstacle is lack of knowledge on the proper selection of indicators needed for overall sustainability assessment. As an example, time and scale of the process, both affect future ecologically sustainable process monitoring. Both ecologically and environmentally sustainable factors and supply chain factors should be carefully considered and optimized. While it is important to assess sustainability using several indicators, it may sometimes be difficult to make business decisions and comparisons among breweries based on a large number of performance measurements (Tokos et al., 2011).

Ongoing activities for sustainability are more likely to focus on an improved calculation of minimal energy demand, which will include electric energy and the consideration of exergy efficiency. Ultimately a comprehensive analysis of different technologies is needed to identify the technology with the best energy and exergy efficiency. Additionally, new (intensified) technologies need to be evaluated for their minimal energy demand. As technological change influences the thermal energy demand and hot water management of breweries significantly, process models for evaluating the best suitable technologies and operating conditions for an ideal heat integrated production site will be necessary. While costly and prone to subjectivity in interpretation, life cycle assessment (LCA) is recognized as one of the most powerful tools available for measuring a product's ecological impact, and for identifying opportunities for improvement. However, new methods should also be developed to provide breweries with transparent, comprehensive and integrated approaches to sustainability assessment, with flexible adjustments for particular circumstances of traditional beer production.

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13 Sustainable Processed Food

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13.1 Early food processing

Since recorded history, foods have undergone various forms of processing before they could be eaten. From these early times, people recognized that processing made some ingredients edible and more digestible, and increased shelf-life. Technologies were relatively simple, such as grinding, heating over fire, or sun-drying, and later salting, pickling and fermentation, but process control and products were dependent on the vagaries of the weather and many other variables. The Industrial Revolution is often marked as the turning point for the development and control of processes to achieve desired outcomes, in terms of quality and quantity. With the combination of the steam power to drive the engines of mechanization, and the development of a system for sealable rigid packaging, canning is recognized as one of the most significant advances in preservation in the very early days of industrial food processing at the beginning of the 1800s. With further advances in this technology in the next few decades, canned food became available in many countries around the world, offering a very extended shelf-life for fruits, vegetables and meats, and a means of reducing food waste due to natural deterioration in quality and safety. Even though there was much more to discover to preserve the sensory appeal and nutritional value during processing and to benefit from the potential economies of scale, these convenient and relatively safe processed foods became important supplies sustaining armies on the move and the many rapidly growing cities worldwide as the Industrial Revolution and colonialist expansion progressed into the nineteenth century. By the next century, commercial processing of food was making major contributions to the safety, convenience and variety of diets for millions of people.

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There were many other technological developments outside the food industry which influenced the growth and success of food manufacturing. For instance, the mass production of refrigerators and automobiles by the middle of the twentieth century made these assets more affordable in many developed countries. Consumers could now purchase, transport and store larger quantities of food safely in the home. Food manufacturers responded to the demand with an expanding range of processed foods, including frozen products such as shelled peas and ice cream. While some products such as fruit conserves and pickled vegetables were familiar because they had previously been prepared at home, others could only be produced using commercial processing equipment, such as the dry, ready-to-eat breakfast cereals. Alongside the staples such as flour and sugar, some dehydrated products were introduced to the market, but canned foods dominated the expanding supermarket shelves for many years.

13.2 Contemporary food processing

Now much more complex, controlled and efficient, contemporary technologies offer many more possibilities. They can be applied to individual ingredients, to the mix, to the packaging or to the process line operations. As well as technologies for heating, dehydrating, cooling and irradiation, extrusion and freeze drying, commercial food processing often involves the application of chemical technologies. Typically, these additives are used to enhance the taste, texture or aroma to make products more appealing to consumers. When fat or sugar or starch or energy content is reduced to assist consumers in achieving dietary objectives, the sensory appeal may be compromised. Selective use of additives can maintain desirable properties such as sweetness or high viscosity or smoothness, potentially compensating for the changes. Many additives are preservatives, making food safe for longer periods, sometimes critical for extending shelf life without the need for energy consuming refrigeration. Genomics have been applied to a range of commodities, such as soya beans and maize, which are converted to a range of ingredients included in many processed foods. Nanotechnology and microencapsulation technologies are changing the way ingredients are integrated into products. Also in various stages of research, cool plasma, ultra-high pressure and pulsed electric field technologies may offer advantages for food processing in the future (Fryer and Versteeg, 2008).

13.3 Consumer conceptions of processed food

Consumer conceptions of 'processed' foods are also relevant here. In markets supplied with processed foods, consumers have come to expect the convenience, safety, variety and availability of these products. However, the negative connotations associated with processed foods as having less than optimum

nutritional value, with higher levels of energy, fat, sugar and salt and lower levels of dietary fibre, can also influence decisions in the marketplace. Associated with processed foods is the information conveyed through labelling. This can be useful for some consumers, but the unfamiliar technical terms can be a source of confusion or suspicion about the safety of a product for others. Consumers may also respond this way to products with very different properties to their component ingredients, made possible by the application of new technologies. Uncertainty about the effects of applying some emerging technologies, particularly genetic modification or nanotechnology, only compounds these concerns. These features all contribute to the conceptions of 'processed food', from the perspective of the consumers in the marketplace.

13.4 The food processing industry

The food processing industry now represents the largest manufacturing sector worldwide. It is as diverse as it is extensive, involving small scale, low technology, localized operations relying on short supply lines through to large, high technology operations, with complex, interconnected lines between suppliers and subsidiaries around the world. Processing operations vary considerably, influenced by convention, regulation, technological capabilities and expertise of employees. The very large global manufacturers tend to be involved in high value added, branded finished products and marketing (Gehlhar, Regmi, Stefanou and Zoumas, 2009; Lillford, 2008). Some companies offer a wide range of products while others specialize, for example, in manufacturing particular commodities such as dairy products, or in supplying very specific markets, such as producing gluten-free foods.

Applying a systems approach to the food processing industry draws attention to the inputs and outputs, locating it in a web of connections and interactions with the primary and tertiary sectors. Demarcation between the sectors is often blurred by the consolidation of supply chains, such as when food manufacturers invest in the primary production of ingredients. Establishing contracts with farmers is one way that companies can assure quality and supply of key ingredients at a particular price (Hamprecht, Corsten, Noll and Meier, 2005). Food manufacturers have also controlled retail sales of their products in various ways, or become more directly involved in the food service sector (Gehlhar, Regmi, Stefanou and Zoumas, 2009). Such arrangements are examples of the ways that companies limit the economic risks associated with competition and the fluctuations in demand. The structural complexity of the food industry, and the associated difficulties in distinguishing between the sectors, add to the challenge of assessing the sustainability of the supply and production systems, and the products of these systems.

13.5 Defining sustainability for food processing

In the report *Our Common Future*, the World Commission on Environment and Development (1987) advanced our understanding of the concept of sustainability. In any one setting, it was seen to be dependent on the status of resources, environmental impact and the less tangible social consequences, and largely a consequence of human activity. Since then, there have been developments in the scope and applications of this concept, but often with considerable differences and dynamism, as is evident when comparing the perspectives of food producers, consumers and other participants along the supply chain (Aiking and de Boer, 2004; Vasileiou and Morris, 2006). Yet we rely on this concept as the basis for developing guidelines for decision making and a framework for assessing the impact of all activities, including food production, on society and the environment. The global nature of the food industry means that there is an imperative for a universal understanding of this important concept and the ways it can be applied.

There have been some important efforts by authorities worldwide to interpret sustainability as it relates to food production systems. For instance, DEFRA (2002, 2006) established a comprehensive agenda for evaluating and communicating the sustainability of food production. Since then, APHA (2007) has defined a sustainable food system as

> one that provides healthy food to meet current food needs while maintaining healthy ecosystems that can also provide food for generations to come with minimal negative impact to the environment . . .

This clearly highlights two important requirements for sustainability, public and ecosystem health. The complete definition identifies other important considerations by drawing attention to the broader social implications of producing and supplying food in the following terms:

> . . . A sustainable food system also encourages local production and distribution infrastructures and makes nutritious food available, accessible, and affordable to all. Further, it is humane and just, protecting the health and welbeing of farmers and other workers, consumers, and communities. (APHA, 2007).

Despite such developments, assessing the sustainability of processed foods remains problematic. As well as the uncertain and varied interpretations of the concept, and the complexities of the supply chain, attention has tended to be on the sustainability performance of the agricultural sector (Vasileiou and Morris, 2006).The particular focus on the environmental impact of farming is probably a legacy of the decades of experience in developing and using tools for environmental impact assessment in the field since the 1960s. Also a consequence of this environmental approach, any assessments of the actual

manufacturing of food have been largely based on energy and resource consumption and the quality and quantity of waste. In these terms, improvements in production are restricted to reduced energy and resource consumption, fewer incidents in which regulatory requirements for emissions and effluents have been exceeded, and more recently to better carbon account balances. In most instances, the associated cost savings mean that there are strong economic incentives to pursue improvements along these lines.

In general terms, making responsible decisions to reduce resource consumption and waste also relies on an understanding of risk tolerance. For this industry, changing process design to reduce energy or water use during manufacture may add to product safety risks, with implications for public health and food security. This broader responsibility extends the analysis of the sustainability of processed food well beyond the patterns of waste generation, resource and energy consumption along the production line.

In this expanded scheme, assessment must also account for the impact of the activities of other industries supplying necessary services to food manufacturers. As in all industries, mass production often relies on large centralized operations, so is very dependent on transport and logistics. Transport from the primary producer to the manufacturer, from manufacturer to retailer, and from the retailer to the consumer, must be included when assessing sustainability. This includes the maintenance and development of transport infrastructure within and outside the company, the roads, trucks, rail and shipping networks. The energy and other resources consumed, and emissions and waste generated by these subsidiary operations to manufacturing, all contribute to the equation when assessing the sustainability of processed food.

Somehow all these costs must be accounted for when making sustainability assessments of processed food. It requires that the impact of operations both upstream and downstream and ancillary to product manufacture is included. While the focus of this discussion is on processed foods, the assessment begins with an outline of the many variables affecting the sustainability of primary produce, which arrives at the manufacturing plant already having accumulated social, environmental and economic costs.

13.6 Primary produce: a key resource for food manufacturing

Although subject to the ways that key variables and approaches to assessment are described and validated, and despite some uncertainties, the scientific evidence demonstrates that human activity is a major driving factor to climate change (Hegerl et al., 2007). The significant growth in agricultural food production has occurred at the expense of many ecosystem services, such as climate regulation (FAO, 2007). Irreversible global warming has been

attributed to the rising levels of greenhouse gases. The effects of CO_2 released through deforestation and burning to clear land for farming are compounded into the future by the loss of capacity of vegetation to absorb this greenhouse gas. As well as the additional CO_2 emissions due to fossil fuel dependence of equipment to plant, harvest and transport produce, grazing animals and some agricultural practices generate methane and nitrous oxide, other important greenhouse gases. Current statistics vary considerably but there seems to be consensus on estimates that agriculture worldwide contributes within the range of 20–30% anthropogenic greenhouse gas emissions. Some calculations have been made of the respective contributions of specific industry subsectors. For instance, the Food and Agriculture Organization (Gerber, Vellinga, Opio, Henderson and Steinfeld, 2010) recently estimated that milk production, processing and transport, combined with subsidiary meat production activities within the global dairy industry, contributes approximately 4% of these gases. Research has also been undertaken on a regional and per country basis, with estimates that agriculture contributed almost 15% of direct greenhouse gas emissions generated in Australia during 2007 (Department of Climate Change, 2009), as an example.

Within the field, plants and animals directly and indirectly rely on the availability of nutrients and moisture in the soil. Sustainable primary produce is the result of practices which protect and replenish the soil for successful future cultivation. There are indications that the products of some common agricultural practices are less than sustainable in these terms. Conventional line ploughing, intensive cropping and overgrazing deplete soil condition, limiting capacity for further production. As well as chemical imbalances, some of the possible physical effects of intensive agricultural practices include erosion or compaction of soil or interference with natural drainage, so affecting production efficiency, sometimes irreversibly.

Sustainability in the primary sector requires access to biologically diverse and productive breeding stock and seed banks. For centuries, food production in the field relied on animal breeds and crop varieties which had evolved through natural selection. In modern times, commercial farming has used carefully controlled selective breeding, and more recently genetic engineering, to develop species offering higher yields or greater resilience against the usual range of climatic and biological risk factors. As a consequence, the genetic diversity of species used in commercial production is reduced. Potentially, this concentration of genetic stock can destabilize the homeostasis and undermine synergies within and between natural ecosystems, further reducing biodiversity. The control over genetic resources raises questions about whether producers will have access to other genetic species with resilient features required to survive the uncertain environmental conditions in the future.

The health and welfare of farmed animals is increasingly raised as a concern in the public domain. Some intensive farming practices are associated with

failing to provide comfortable and adequate animal housing, to the extent that instinctive behaviours are inhibited in some instances. Controlled feeding regimes, antibiotics or hormones may be used to promote growth at the cost of animal well-being. At this end of the supply chain within the primary sector, sustainability also depends on the humane killing of animals, including strategies for minimizing pain and distress at this point. As an example, the mistreatment of cattle involved in live export trade jeopardized the economic sustainability of this primary industry in Australia (ABC Rural, 2011 6 June). Intensive farming of animals is also associated with considerable problems of effluent and other waste management. In particular, the risks of disease transfer within species and to humans when animals are contained for intensive farming, compromise the sustainability of operations, as was evident with the outbreaks of BSE in Europe.

Recognizing and measuring the social impact of primary production, and associated ethical considerations, extends to the people involved in this sector. For instance, safe and culturally and socially acceptable working conditions, as well as fair market rates for work and produce are widely recognized as requirements for long-term stability and well-being in farming communities. A range of indicators of social sustainability were piloted for these workplaces some time ago (MAFF, 2000), and research is continuing to develop and adapt them for specific industry sub-sectors, and to integrate them with measures of ecological and economic sustainability.

A range of alternative food networks have developed alongside the dominant large scale agricultural systems for food production in response to many factors, including public concerns about animal welfare and the environment. Many of these initiatives involve more community-based operations, with shorter and more direct links to the consumer (Ilbery, Watts, Simpson, Gilg and Little, 2006). They tend to rely less on technological innovations and more on older traditions in farming, including food processing and preservation on the farm. Some examples of practices which are part of these alternative food networks include organic and permaculture production methods, heritage seed banks and animal breeds, fair trade movements and farming cooperatives. Sometimes these short chains extend to retail outlets, such as farmers' markets, allowing for more direct transactions between producers and customers, so by-passing the mainstream manufacturers. In the past, the small scale production reliant on these practices made them unsuitable as sources of ingredients for mass food manufacture. However, a number of large food companies have been able to access organic and fair trade certified produce, sometimes through investing in sustainable agricultural production of key ingredients. Such initiatives have enabled them to make sustainability related claims about some of their processed products in response to changing consumer demand. This control of primary production also means that corporate decisions can affect farming communities, as well as consumers.

13.7 Technological innovation for sustainability

Even for basic commodities, the range and complexity of technologies applied in processing varies. The energy consumed and solid wastes, emissions and effluents generated in processing of a wide range of commodities have been calculated (See for example, Dieu, 2009) to distinguish more and less sustainable ingredients from this perspective. The sustainability of specific technologies can also be characterized and compared in terms of energy costs. For instance, heat transfer systems in US manufacturing have been estimated to have the most demanding requirements by far (ICF International, 2007), and global trends are probably similar in this respect. As well as the commodities and technologies used in processing, the sustainability of a product is dependent on other requirements, such as packaging. There are some manufactured products which are not sustainable, according to this relatively simple approach. A carbonated, artificially sweetened drink in an aluminium can was identified some time ago as an example of a very resource and energy intensive product, offering only hydration as a metabolic benefit (Gussow and Contendo, 1984). In comparison, tap water could satisfy this need in a much more sustainable way. The design of such products has been based on past assumptions about ongoing access to abundant resources, and about the capacity of the planet to absorb or degrade wastes without interfering with natural systems. These assumptions have been challenged now for decades so that there is a strong consensus about the need for change from obviously unsustainable to more sustainable practices in food production (Schacht, Filho, Koppe, Struksnaes and Busch-Stockfisch, 2010).

Change does not necessarily mean reverting to pre-industrialized small scale food production practices which relied on manual labour and simple technologies. There are many reasons for appreciating contemporary artisan products which are typically reliant on these traditional methods. They can contribute to the pleasure of eating, to supporting local economies and to preserving aspects of culture, but this relatively small sub-sector of the food industry cannot supply billions of hungry people.

Innovation has been recognized as the key to commercial success for food manufacturers supplying a very large, but often very crowded and competitive marketplace. Genetic engineering and nanotechnologies are opening up possibilities never before considered, and many large multinational food companies have well established research programmes in these areas. The science of genomics has been applied to the production of plant and animal based foods, but also to the mapping of human genes, and so to nutrigenomics, the science identifying ways to moderate individual health risks through diet (Boland, 2008). Nanotechnologies offer the promise of controlled and targeted delivery of nutrients and other health protective factors, or to reduce absorption of fats and sugars. With this knowledge come the opportunities for developing designer foods, customized to individual metabolic health requirements or sensory preferences.

For some time, concerns have been raised about the possible risks of producing and consuming genetically modified foods (Curtis, McCluskey and Wahl, 2004). These concerns now extend to the application of nanotechnologies. The science explaining these technologies is very technical and complex, so difficult for the public to understand and assess risks (Banati, 2011). The reporting of adverse effects or events, accurately or otherwise through the mass media, such as the inadvertent release of genetically modified seed into the environment or the leaching of nanoparticles from packing into food, can contribute to consumer distrust of foods developed through such high technology innovations.

Consumer preferences for local, ethnically authentic, traditional or organic foods produced using simple technologies have placed new demands on food production. One approach is the maintenance or building of segregated food chains with the capacity to preserve source identities. Such chains rely on information technologies for control and monitoring to allow valid claims about origins and treatments, beginning in the field and extending through to dedicated processing lines. As indicated by the increasing availability of processed foods with validated organic status, some manufacturers have been able to successfully integrate these alternative supply chains into mainstream production.

Despite the public concerns, high technology solutions are compatible with sustainability. Annual reports and websites of many multinational food companies describe the significant advances in terms of economic savings and environmental benefits already achieved through innovations which reduce energy and water consumption during processing. Beyond the actual processing of the food, technology might lead to re-designing unit and bulk packaging to reduce the materials required for containing and protecting the food or to make packaging reusable or recyclable. It may extend the shelf life of products so reduce waste in the retail or domestic sectors. However, innovation for sustainability relies on improving a much broader range of parameters, beyond the cost effectiveness or efficiency of operations and local environmental benefits. The social and cultural impact of innovative products must be also be accounted for in deciding whether they should proceed to the marketplace. This includes the contribution of these products to human health and well-being.

13.8 Health and well-being

Access to an adequate and nutritious food supply is the means to protecting health and well-being, so a requirement for sustainability. Most mainstream diets in developed countries include a large proportion of manufactured foods. Essentially, sustainability requires that these products contribute to balanced and adequate nutrient and energy intakes. The nutritional value of a processed food is dependent on the naturally occurring levels of nutrients in the

ingredients, and then the effects of processing on nutrient concentration and bioavailability. Depending on the processing conditions, nutrients may be lost due to the combined effects of a range of variables, including their solubility in water or fats, their sensitivity to heat, light, pH and oxygen. On the other hand, bioavailability may be increased with some of the changes during processing or through synergistic effects between product components which increase nutrient uptake. More generally, processing technologies may contribute to public health objectives through optimizing nutrient retention or nutrient uptake or through the manufacture of products which make it easier for consumers to follow recommended dietary advice.

Important attributes which influence food choice, convenience and sensory appeal, are a consequence of the ways ingredients are combined and processed. Food technologies provide opportunities to create very different compositions and properties, as compared to fresh commodities. In response to consumers' preferences for flavour and convenience, many conventional processed foods tend to be energy dense, with relatively high levels of sugar, fat or salt, (James, 2008). Although many factors are involved, obesity and many of the chronic degenerative diseases facing contemporary populations have been attributed to the consumption of low cost, readily available products with these attributes (Lowell, 2004). In response to public health regulators or consumer concerns, manufacturers have exploited the opportunities afforded by new technologies to modify formulations so there are now alternatives with lower levels of fat, salt and sugar or higher levels of protein or dietary fibre, effectively re-positioning many conventional products in the marketplace. The potential health benefits of substituting conventional products with these alternatives on a population basis are difficult to assess. However, the wide range of energy-reduced or composition-modified products now available seems to have had little effect so far on moderating the growing incidence of obesity and diet-related diseases in more affluent countries.

Food processing also provides opportunities for product supplementation or fortification, with potentially substantial health benefits. Historically, governments in many countries made it mandatory to supplement or fortify specific staple foods, or staple food replacements, with vitamins and minerals to avoid widespread deficiencies. This practice continues with margarines and infant formulas supplemented with vitamins A and D, flour and processed breakfast cereals with B vitamins as examples. More recently, this practice has extended to supplementing or fortifying foods with other biochemically active agents, such as antioxidants or plant sterols, agents which have the potential to illicit human metabolic responses promoting well-being. Depending on the regulatory environment, adding these substances may allow health claims to be made or implied. However scientific knowledge about their role and effects is often incomplete, so the benefits are not readily predicted (Desmarchlier and Szabo, 2008). Prospective

health benefits may also be compromised by unanticipated interactions between product components. More serious is the potential for some less than desirable reactions in some individuals, such as reduced efficacy of prescribed medications or interference with absorption of nutrients provided through other food sources.

While the food industry made an enormous contribution to reversing the deficiency diseases in many countries, new health problems place different demands on the food supply (German, 2008). Sustainability requires that individuals with conditions such as cardiovascular disease, diabetes type 2 or hypertension, have access to modified products suitable for maintaining their metabolic well-being. Consumer interest in personalized nutrition is recognized as a major trend influencing product development in the food industry (Thompson and Moughan, 2008). For decades, manufacturers have demonstrated a capacity to respond to different needs, as exemplified in the ever expanding range of carbohydrate modified products suitable for the growing population of individuals affected by diabetes. More than this, some manufacturers have taken steps to provide detailed information through printed material or on their websites, even establishing links there to other resources to assist these consumers. Such initiatives could potentially enhance the sustainability of processed foods, if they enable and even encourage consumers to make informed choices about their diet.

Choosing a varied diet is probably the only unequivocal and universally appropriate population-based dietary recommendation. The chance of dietary imbalances or nutrient deficiencies is reduced when many different foods are regularly consumed in moderation. So, one important indicator of the sustainability of any food-related initiative is its impact on diet variety. On this count, manufacturers contribute to sustainability in reliably supplying a wide range of safe and appealing products. However, manufacturers rely on marketing to make their products more conspicuousness amidst the array of alternatives available. In emphasising the benefits of a single product, advertising can appear to contradict reliable public health information promoting moderation and diet variety.

As well as nutrition, health is dependent on psychological status, indicated by parameters such as self esteem, which develop with a sense of belonging to a group or community, often manifested through participating in traditional customs. The food supply is an important variable determining how individuals, families and other social groups engage in cultural practices which often involve sharing meals. On the one hand, the added convenience of processed traditional foods suggests that it may be easier to practice the social rituals surrounding eating and cooking, particularly in the context of contemporary busy life styles. On the other hand, if manufacturers divert traditional or staple foods into complex supply lines, supplies become scarce. This can undermine the capacity for social or cultural expression, particularly in circumstances where economic and other resources are limited. Rather than being able to

generalize here, assessing the sustainability of processed food from this perspective must be done on a case by case basis.

13.9 Food security and sustainability

An important consequence of the existing production systems is the extraordinary amounts of processed food which goes to waste from commercial and domestic settings in developed countries (see for example, Baker, Fear and Denniss, 2009; Ventour, 2008). Errors in any large scale processing decisions in the factory are inevitable. Weather extremes, cancelled events, new health information or even food scares can cause sudden changes in consumer demand. Combined with the usual mishaps and mismanagement of food within the household, the overall waste means substantial economic losses for manufacturers and individuals. There are also additional demands placed on the capacity of ecosystems to degrade the waste, so there are very significant environmental costs. Sustainability requires much more than a commitment to balancing demand and supply, because many of these factors are difficult to predict, control or avoid. It requires recognizing the opportunities to redirect this waste by connecting with other systems not traditionally considered to be part of the supply chain.

The well-documented global phenomenon of food insecurity describes patterns of inequities in access of this most basic of resources. For some time many food companies worldwide have been diverting production surpluses to make donations to support vulnerable groups in society affected by food insecurity. There are now many agencies which facilitate the distribution of excess products, and with changes to legislation and regulation in some countries, they transfer safe processed food through these extensions of the traditional supply chains. As well as contributing to protecting the health of these vulnerable individuals and reducing the burden of biodegradation on the environment, there are other potential benefits for companies. Through their annual reports and websites, companies often refer to these initiatives as ways they meet their social responsibilities, so potentially building goodwill and creating a positive public image. Demonstrating social responsibility has been recognized as a form of value adding for a long time (Adams, 1990). When food companies consistently integrate such extensions into mainstream operations to benefit broader society beyond their customer base, processing becomes more socially responsible and sustainable.

13.10 Communications with consumers: Labelling and marketing

Many many years ago, conventional wisdom about food and nutrition was conveyed by word of mouth from one generation to another. With rapid

technological innovation and short product life cycles associated with modern food manufacturing, it has not been possible to make and accumulate useful generalizations about the relationship between the attributes of many processed foods and their nutritional properties. Consumers' understanding of their food and its origins, of its contribution to a balanced diet, of how it should be prepared, or how much comprises a suitable serving size, is limited when it is the product of complex technologies. Faced with these complexities, there is an increasing reliance on manufacturers for information about processed foods, provided mainly through food labelling and marketing. How manufacturers respond to this onerous responsibility influences the sustainability of processed foods.

Mandatory nutritional labelling of most processed foods had been introduced in many countries by the 1980s, to enable consumers to make informed dietary choices to protect their health. Since then, a considerable body of research has reported the difficulties they experience in using the label, and particularly the nutrition information provided (see for example, Cowburn and Stockley, 2005). As a way of dealing with a relatively complex set of information, consumers often refer to a single nutrient, typically fat, salt or sugar, as a basis for making a decision. Interpreting the label and marketing messages describing the health protective features of a processed food in terms of their personal needs represents a major challenge for most individuals.

The contribution of a food to recommended daily intakes of vitamins and minerals might be considered to be an objective standard, which could be used to distinguish between products. However, even human nutrient requirements are interpreted variously by authoritative bodies around the world, despite the scientific research and evidence accumulated over many decades. This adds to the challenge of developing labels offering universally useful information about the nutritional value of processed foods when they are distributed globally.

The growing public awareness of the realities and risks of climate change has contributed to changing expectations of food manufacturers. Consumers are interested in knowing how decisions in this sector are affecting sustainability. As well as value for money, they now consider the social and environmental performance of companies when making choices between brands and types of processed food. In most instances, labelling and marketing are the main routes through which this information reaches consumers.

There have been considerable advances in developing coding systems for labels, using symbols, logos or phrases to indicate more sustainable practice somewhere along the processing chain. Inevitably, translating and summarizing complex information about the environmental and social impact of production in meaningful ways presents difficulties (Hoogland, de Boer and Boersema, 2007). More than this, the usefulness of this information is limited by consumer scepticism about claims they cannot verify (Harris, 2007; Verbeke, 2007). Even if claims are legitimate, the sustainability of processed

foods relies on establishing consumer trust and on using reliable, tested strategies to communicate the information.

13.11 Stakeholder participation

Sustainable systems are participatory in nature. For processed food, this requires that decisions involve the primary producers and wholesalers supplying the ingredients, subsidiary service providers and consumers, as well as the manufacturers. Stakeholders can be involved in many different ways, depending on their roles, interests and expertise. They may exert a very direct influence on the resources consumed, such as when a distributor decides on using low emission transport to deliver commodities to a manufacturer, or when a subsidiary company supplies the manufacturer with electricity generated by renewable energy sources rather than fossil fuels. There have been calls to establish effective means of dialogue with consumers about manufacturing decisions (Caspi and Lurie, 2006). Despite the obvious challenges, this can be achieved through a range of participatory processes, including inviting stakeholders to online forums or workshops (Shepherd, 2008).

There are many types of relationships between food processing companies and stakeholders. Relevant here are the traditional ‘commercial-in-confidence’ agreements with stakeholders, often associated with costly and innovative product development. Typically, they require very limited disclosure about the formulation or processing involved. While the economic case for this arrangement is understandable in such a competitive environment, it is potentially a barrier to participation of all stakeholders, and so to sustainability. The benefits of this approach to innovation must be weighed against the cost of limiting information exchange about the products.

Many food companies have recognized that partnerships with external stakeholders, including other manufacturers, can lead to initiatives which are essentially good for business because they can minimize risk, assure quality and delivery of products, and respond more efficiently to changing consumer demands (Smith, 2008; Yach, Khan, Bradley, Hargrove, Kehoe and Mensah, 2010). Such partnerships have led to the implementation of important health promotion programmes which might otherwise not have been funded (see for example, Mortarjemi, 2006).

As representatives of the public, regulators are important stakeholders in food manufacturing decisions. Regulation of food varies considerably from one country or region to another, making it difficult to generalize about its contribution to sustainability. On the one hand, impartial and well-informed regulation combined with the capability for monitoring and enforcing standards can ensure products meet safety or nutritional standards, important requirements for sustainability. On the other hand, without the resources or authority to review, update or implement standards, a regulator becomes less important as a contributor to the sustainability of processed food.

Collaborative arrangements depend on the objectives and values of the stakeholders. For instance, a company committed to sustainability could influence the wholesale marketplace culture by forming voluntary partnerships with stakeholders there, so costs and benefits are equitably shared. Paying a fair price, or even a premium, for ingredients produced sustainably could affect agricultural practices within the primary sector. Establishing fairtrade agreements with primary producers allows food companies to demonstrate corporate social responsibility, while meeting consumers' expectations about their food.

Referring to a specific example is useful here. In 2003, the Roundtable on Sustainable Palm Oil (RSPO) was formed as a collaboration between non-government organizations, including WWF and Oxfam, palm oil producers, processors and traders, food manufacturers and retailers, banks and investors (RSPO, 2009). Palm oil is widely used in processing, because it is a relatively inexpensive lipid source, has a longer shelf life than butter or other vegetable oils, and is stable under conditions during product manufacture. The continued use of this source has been considered to be unsustainable for two main reasons. Palm oil contains medium chain length saturated fatty acids which have been shown to contribute to cardiovascular risk. Secondly, to meet the demands of food manufacturers, extensive palm oil plantations have been established, sometimes at the expense of deforestation and destruction of native habits of many endangered jungle animals in tropical regions. Many food companies worldwide have become members of the GreenPalm programme, making commitments to use only palm oil certified as sustainable. While there have been some improvements in the stability and manufacturing performance of other oils which could replace palm oil, certification through the GreenPalm trading system offers companies an immediate incentive to make their palm oil containing products more sustainable.

Employees are important internal stakeholders in food manufacturing. Just as in the primary sector, a sustainable workplace ensures employee safety, and minimizes negative outcomes such as injury on the job, employee or production down time due to work related injury and incidents. More than this, work should provide opportunities for personal development, and wages considered fair when compared to local minimum and median income levels. Offering above award salaries, accommodation allowances, access to leisure facilities during work breaks, health insurance, flexible or shorter full time work hours are some ways that employers can ensure satisfying experiences for workers. These conditions are often the result of an effective collaboration between management and worker representatives. The frequency with which legitimate issues are raised, and outcomes achieved in terms of meeting real employee needs, as well as the avoidance of disputes, are some indicators of the effectiveness of this dialogue. Failing to meet satisfactory conditions for employees, as important collaborators in the supply chain, compromises the sustainability of products of the system.

As a starting point to forming collaborations for sustainability, it is necessary to identify the stakeholders and their responsibilities for the management of people, resources and wastes along the supply chain. Sustainable production then depends on action to convene key stakeholders who are authorized to make changes, and then on their capacity to exert fair and reasonable influence in decision making. Effective partnerships rely on mutual respect, openness, effective and ongoing negotiation, and sometimes compromise, by all parties. Once on this footing, stakeholder and company agreements need to be documented, so fully reportable, making all parties accountable for the decisions.

13.12 Reporting and risk management

Sustainability relies on capacity to accurately predict outcomes of production, so depends on access to data describing important inputs and outputs along the processing line. This data must reliably indicate the current status of key features within a system, and in a form which can be readily analysed and then extrapolated responsibly to predict future trends. It must be useful and accessible for all stakeholders involved in the decision making, so may require simplification of highly technical information. This is particularly important for communicating information about risks, when experts' and other stakeholders' understanding of the underlying scientific issues are likely to differ (Shepherd, 2008).

Reporting needs to be a priority for companies, so undertaken regularly and rigorously, with information exchanged through organized channels (Wognum, Bremmers, Trienekens and van der Vorst, 2011). This is not incidental or insignificant reporting, but systematic and comprehensive, describing sourcing practices, activities and outcomes in the workplace and marketplace. It must be complete, so acknowledging the less than successful attempts to improve sustainability of products or processes, as well as the more successful initiatives.

Making information sharing a standard practice within a company may reduce the need for employing costly consultants for problem solving. Encouraging information sharing between divisions and employees within a company utilizes the intelligence gleaned through years of experience so can lead to more effective solutions and better risk management. For instance, employees may have ideas about safer processing operations, more efficient process line sequences or transport logistics, or better use of infrastructure during on- and off-peak production periods. On the factory floor, encouraging employee participation in decisions means problems are anticipated and controlled, reducing the risk of costly product recalls later or the potential damage to public image when products fail to meet expected standards in some way.

For employees to report problems and propose solutions requires confidence about job security and a culture of trust within the workplace. In difficult economic times, companies generally find it harder to provide such assurances.

However, efforts to justify this trust may more than outweigh the costs. As well as the opportunities for more productive innovation, the potentially more satisfying work experience for employees correlates with higher retention rates, reducing the costs of induction and training, so contributing to the economic as well as the social dimensions of sustainability of the products of their work.

13.13 Tools for assessing sustainability

Assessment tools typically include a set of key performance indicators for sustainability, with criteria describing the standards relevant to each indicator. Developing these indicators and criteria relies on a sound knowledge of the system, the important variables and the variances in inputs and outputs. More than this, indicators need to be transparent and understood by individuals involved in collecting information and making assessments at all points within the system boundaries.

It is difficult to envisage a universally relevant set of parameters and criteria for assessing the sustainability of processed food, given the diversity of the food manufacturing industry, let alone accounting for the impact of operations in the other sectors on which manufacture is dependent. Clearly, the tool must be adaptable to the size and nature of the operations, even the location of the factory, accommodating the prevailing political, cultural and legal systems pertinent to operations there. It must allow valid comparison of outcomes of initiatives to be made, so that more effective options can be identified. Importantly, the assessment must be sensitive to change so can measure progress within a company and identify areas where improvement is required. Finally, the outcomes of assessments must be fed back into the system and used to drive decisions at the micro and macro levels. Ideally, the assessment criteria can be objectively interpreted and applied to distinguish more sustainable operations, so exposing practices or models which other companies can adopt.

With different parameters taking precedence as the commodities move from the primary to the secondary sector for processing, it is understandable that several tools may be required. Using more than one tool requires a seamless carryover from one to the other. This approach aligns with the principles of Life Cycle Assessment. This type of assessment is potentially broad in its scope, and has been shown to encompass many variables when applied to the food supply chain, including the nutritional quality and safety of foods, the implications of waste product and packaging at the point of consumption, and the influence of marketing and other messages on food choice and health. Opportunities and conditions of employment have also been accounted for in life cycle assessments. Such analyses have shown that a product of a shorter supply chain may not necessarily be more sustainable when a full account of the carbon emissions over the life of the product is undertaken (Institute of Engineers, 2009).

As well as being industry specific, the food processing sector supplement of the Global Reporting Initiative (GRI, 2010) offers a systematic and comprehensive approach to identifying and reporting on the key issues and a wide range of pertinent indicators of sustainability of operations within food companies. Using this tool, indicators of progress include the introduction of sustainability related specifications for ingredients, greater proportions of ingredients from sustainable sources, and contributions to building of supplier capacity for compliance with sustainability related standards. Reducing emissions, effluents and other waste during all stages from receiving raw materials through processing to product distribution are other important targets for sustainability, as outlined in the GRI. More significant is the inclusion of social indicators of performance in marketing and labelling, customer health promotion and labour relations.

For many large companies, the social impact of operations is often expressed in terms of meeting corporate social responsibilities. Companies are increasingly making fundamental changes to protect and promote their public image as good corporate citizens. Virtually every website of major companies describes different ways they demonstrate their corporate citizenship, even in regions quite remote from the marketplaces they supply. More than reducing consumption of water, energy and other resources, and minimizing harmful wastes, many companies are proactively considering ways to contribute to sustainability through a diverse range of initiatives (see for example, Chastain, Vis, Smith and Chahley, 2009; Cramer, 2007; Green, 2006).

Despite these efforts, only a few tools acknowledge and integrate the social, economic and environmental indicators required for a comprehensive assessment of sustainability (Singh, Murty, Gupta and Dikshit, 2009). While social responsibilities might be acknowledged in mission or vision statements or annual reports, social outcomes are typically less quantifiable and less easily measured than economic and environmental outcomes. This might explain why social indicators are varied and inconsistently applied by companies (Delai and Takahashi, 2011). Integrating corporate performance in an assessment of sustainability invites questions about the relative importance of initiatives, particularly where there are competing interests. When commitments to protecting the environment and supporting communities and broader societal structures are perceived to be in conflict with core business, companies have difficulties in describing indicators, setting benchmarks, planning and implementing the changes needed for sustainability (Steger, Ionescu-Somers and Salzman, 2007).

13.14 Conclusions

The more affordable, reliable and varied food supply, in large part due to commercial food processing, is probably one of the most important factors contributing to the improving standards in public health through the twentieth

century. Since then, our realization of the scope of sustainability extends our understanding of the impact of food manufacturing. The lens of sustainability highlights the very wide boundaries of the food processing system which includes communities and consumers, regulators and government, subsidiary service providers, as well as commercial manufacturers. Applying the concept of sustainability to processed food demands a systematic and logical approach to examining the complex interrelationships at different points along the whole supply chain. With the primary producers positioned at the start of the supply chain, it is inevitable that costs incurred here are included when evaluating the sustainability of processed foods.

The dependence on the primary sector for raw materials implicates a whole range of farming practices, from the ways animals are treated, the use of agricultural chemicals, through to working conditions and impact on the surrounding community. The CO_2 emissions through fossil fuel burning to drive planting and harvesting machines, combined with the loss of biological capacity for CO_2 absorption as land is cleared for crops and grazing, all compromise sustainability. Measuring CO_2 output in producing the raw materials for manufacturing is a useful quantifiable starting point for assessing sustainability in the primary sector, although it is quite incomplete.

The importance of food for personal and cultural expression adds many more dimensions to this system. It means that sustainability is dependent on action which respects cultural diversity, and preserves the social rituals which allow expression of cultural identity. The sustainability of processed foods must be judged in terms of these requirements. When the food supply offers many novel foods, derived through the interplay of market research and technological capabilities, opportunities to recognize, express and reinforce cultural and social identity through food may be affected. This might also occur if supplies of staple traditional foods in subsistence communities are diverted or disrupted to meet the demands of mass production.

The need to cover the high costs of product development and marketing has tended to unfavourably moderate the balance between nutritional value and price for some of the more innovative products of recent decades. Technological innovation has also led to many new and unfamiliar foods with unique compositions, sensory properties and applications, adding to the difficulties consumers experience in making food choices to protect health. Introduced to address the gaps in public knowledge about food composition, mandatory regulated product labelling has some limitations in conveying the necessary information in meaningful ways for consumers. From their perspectives, the persuasive marketing of manufactured products sometimes competes with authorized messages about dietary balance, variety and moderation. As a consequence of practices in product innovation and marketing, manufacturers have been accused of creating an environment conducive to obesity and other health problems, rather than being recognized for contributing to public health through assuring a secure and safe food supply.

Sustainability requires effective communications with consumers, offering useful advice about composition that allows them to distinguish those products potentially contributing to balanced diets, so more than complying with minimum regulatory standards. The distribution of products to a global market raises issues about communicating a general message to population groups with diverse needs. A company concerned with sustainability might consider ways that advertising messages could responsibly support authorized dietary advice or refer consumers to more detailed sources of information. The manufacturer might extend a product range to include safe alternatives to meet different needs in the community, even when the opportunities for profit are limited. This means that an evaluation of the sustainability of a product must take into account the quality, reliability, accessibility and usefulness of that information from these sources, and whether, on balance, it enables and encourages health protective choices.

As well as information about nutritional value, consumers are choosing according to an increasingly diverse range of product attributes, including production methods, ingredient origins and food miles. Consumer trust in the manufacturing sector to exercise adequate care of the natural environment and society relies on companies relaying information about performance in these areas. In particular, applications of genomics and nanotechnology in food processing have raised public awareness about the potential environmental and social impacts of production. Assuring traceability through reliable auditing has become an important activity for the food industry, and necessary for building consumer confidence. This requirement has changed the ways manufacturers organize the supply of raw materials, often making products more sustainable.

The sustainability of processed foods relies on ensuring input from all key stakeholders to minimize risk, resource consumption and waste, both internal and external to the organization. Sustainability of products is enhanced when such arrangements are mutually beneficial and collaborative and ongoing, so are integral to the mission and vision of a company. While sustainability makes manufacturing decisions more complex, it has introduced many opportunities. In rising to the challenge of integrating ideas and feedback from stakeholders, the risk of unsuccessful commercial decisions is reduced. The process exposes opportunities to support communities, enhancing public image and creating good will, so building customer loyalty and trust, important predictors of success in a crowded marketplace.

The commercial production of food involves many practices which affect sustainability in very significant ways. There is no blueprint for making decisions and managing operations for sustainability. Each company must identify the options, given the constraints of location, size, supply networks, product range and market. To identify these options requires a regular review of the needs of customers and society more broadly, of their product range, ingredient sourcing and processing capabilities, as well as outsourced

functionalities, such as transport, energy supplies and waste disposal. To manufacture sustainable processed foods requires that companies take action to address the needs of the future as well as the present. Predicting options for the future requires a commitment to researching ways to minimize the negative impact of current and proposed operations. Rather than considering research as a costly activity, sustainable processed food comes from companies which recognize that research is a cost effective means of assuring long term success.

A sustainable product is the result of a sustainable system. Assessing sustainability of processed food requires looking beyond the immediate costs of production to the complex accounting of the impact of all company activities. Some tools have been adapted and extended to measuring the demands of processing, transport and storage in food processing. However, the focus has been on economic and environmental indicators, which tend to be more clearly identified and described. Many companies have measured the social impact of processing food in terms of the concept of corporate social responsibility. The problem here is that this concept has not been interpreted to consistently include the very extensive net of social determinants of sustainability, and reports of corporate performance may not be integrated with the environmental and economic outcomes.

A number of tools have been developed to assess determinants of sustainability in food processing. Applying and developing these tools further will uncover ways to more fully realize the scope and interrelationships between of all these determinants, and how the outcomes can directly influence day to day decisions in manufacturing. This is fundamental to progress towards a complete assessment of the sustainability of processed food.

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Section 3

Food Manufacturing Operations

14
Concept of Sustainable Packaging System and Its Development

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14.1 Introduction

Packaging plays an important role in modern society by providing protection from physical damage, ease in handling, transport, and, most importantly safety of the inner products. Packaging can be classified into three categories: primary, secondary and tertiary. Packaging materials in primary forms are largely mixed, contaminated and often damaged, and therefore, create problems in recycling or reuse. Secondary and tertiary packaging materials are relatively easier to collect and sort for recycling or reuse purposes (Davis and Song, 2006). Over 67 MT of packaging waste is generated annually in the EU which represents one-third of all trash (Klingbeil, 2000). Current recovery rates for packaging are also very low, with most packaging waste ending up in a landfill. For example, the national recycling rate in Canada is 25% and the household recycling rate of all materials is about 52% (Statistics Canada, 2007).

In recent times, sustainable packaging has been adopted by some industries and business houses, either as a repackaging of environmental policies in the language of sustainability, as a marketing strategy in response to social pressures or, as a genuine attempt to grapple with the commercial, social and environmental issues associated with packaging (Young et al., 2001). Now companies want to provide more sustainable products and be more sustainable

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in how they operate. Within this context, packaging is a high profile issue that must be considered in a company's sustainability strategy (SPA, 2012). Many tools have been developed to support design for sustainability. The life cycle assessment (LCA) which evaluates the life cycle impacts of packaging represents the 'perfect tool' for working on such a procedure (Siracusa et al., 2011). Packaging Impact Quick Evaluation Tool (PIQET) a new web-based business tool has been introduced for rapid packaging environmental impact assessments. PIQET is used to optimize packaging system design from a sustainability perspective in all stages of the product development process (SPA, 2012). A more recent development in this area is increasing demands for product stewardship, which requires greater responsibility of manufacturers for the life cycle management of their products. This chapter focuses on a holistic approach for food packaging and its sustainability.

14.2 History of sustainable packaging and definition

The Sustainable Packaging Alliance (SPA, www.sustainablepack.org) was formed between three Melbourne (Australia)-based organizations: the Centre for Design (CfD) at RMIT University, the Packaging and Polymer Research Unit at Victoria University and Birubi Innovation in 2002. The founder SPA partners recognized the need to develop an integrated, supply chain focused, multi-dimensional approach to research, education and training (James et al., 2005). The SPA released definition of sustainable packaging in 2004 and revised it in 2007 by adding the key performance indicators. According to SPA, the sustainable packaging should meet the following four principles: (i) packaging should be effective (both cost-effective and functional for all the users in the value chain), (ii) efficient (using material resources and energy as efficiently as possible), (iii) cyclic (enabling recovery through industrial or natural systems) and (iv) safe (as non-polluting and non-toxic and therefore not posing any risk to humans and ecosystems). The SPA's definition was more acceptable from the others since it defines sustainable packaging in terms of its performance throughout the life cycle, not only how it performs at the end of life. The definition also focuses the function and purpose of packaging and is directional and not prescriptive.

In 2004, GreenBlue launched the Sustainable Packaging Coalition® (SPC, www.sustainablepackaging.org), a parallel organization to SPA in North America with nine founding member companies and with funding from the US EPA. The SPC is an industry working group dedicated to a more robust environmental vision for packaging, and its vision to build packaging systems that encourage economic prosperity and a sustainable flow of materials. According to SPC, the sustainable packaging should incorporate the following criteria: sustainable packaging is beneficial, safe and healthy throughout its life

cycle, meets market criteria for performance and cost based on renewable energy throughout its life cycle, optimizes the use of renewable and recycled materials, and best practices, follow the best packaging design to optimize materials and energy.

The Canadian Council of Ministers of the Environment (CCME) has formulated a strategy to reduce packaging waste in Canada and promote more sustainable packaging choices. The Extended Producer Responsibility (EPR, www.ccme.ca) Task Group, formed in 2005, reports to CCME's Environmental Planning and Protection Committee. In 2007 CCME approved the Canada-wide principles for extended producer responsibility. EPR is an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle.

Sustainable packaging is reality today and all the credit goes to SPA for taking an initiative, and formulates the basic framework, which facilitates the reaching of sustainability objectives. However, further directions on how to implement these principles and indicators to the processes of both product and package design are still missing. In some occasions (e.g. relating to different materials or different operational environments), some principles or criteria may be more important than others (Grönman et al., 2012).

14.3 Concept of sustainable packaging

The issue of sustainability is high in the environmental platform for a number of years, encouraging academia and industry to develop sustainable alternatives, thus aiming to preserve resources for next generations. At the same time, these sustainable alternatives address other key issues such as the use of surplus stocks of food and the production of higher added value agricultural products thereby promoting economic development in the agricultural sector. The successful promotion and use of biological, renewable materials for the production of packaging materials would satisfy a number of the key objectives. The packaging materials mostly obtain from non-renewable materials. Paper and cardboard are mostly used for renewable packaging materials which are basically originate from cellulose, the most abundant renewable polymer worldwide. Still, searches are going on to identify alternative non-food uses of bio-based packaging materials. Eco-friendly bio-composites from plant-derived fibre (natural/biofibre) and crop-derived plastics (biomore plastic) are novel materials of the twenty-first century and would be of great importance to the materials world, not only as a solution to a growing environmental threat, but also as a solution to the uncertainty of petroleum supply (Mohanty et al., 2000). The biopolymers or biocomposites provide an excellent opportunity for the material engineer to incorporate a very appealing functionality into the material, that of compostability. In recent times, polylactides, poly(ε-caprolactone), starch-derived materials and composites have been experimented with and somewhat successful in that direction. Sustainability has become one of the essential makeover trends within food packaging.

In addition to the emergence of biopolymers in the area of packaging, the next challenge lies in package design and finding a good balance between the product and the packaging. Details of packaging design are discussed in a separate section. For sustainability packaging design, it is necessary to understand the environmental impacts associated with all aspects of producing, using and disposing of a product and its packaging (Verghese and Carre, 2012). Life cycle assessment (LCA) and life cycle inventory (LCI) are commonly used terms to determine the sustainability of packaging materials all over the world. Life cycle assessment (LCA) is the investigation and valuation of the environmental impacts of a product or service with the goal of comparing the full range of environmental damage assignable (ISO, 2006). The life cycle inventory (LCI) quantifies material use, energy use, environmental discharges and wastes associated with each stage of a product system over its life cycle, from raw material extraction to material processing, product fabrication, use, reuse or recycling, and ultimate disposal (ISO 2006).

Sustainable packaging is a relatively new term in the packaging industry. It requires more analysis and documentation to look at the package design, choice of materials, processing and life cycle. The films should be preferably biodegradable and provide superior oxygen barriers to petroleum-based films. The goals are to improve the long term viability and quality of life for humans and the longevity of natural ecosystems. Sustainable packaging must meet the functional and economic needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is not necessarily an end state but is a continuing process of improvement. More researches are needed to improve the moisture barrier properties of the agro-based film, but advances in sustainable packaging are actively being pursued. It is worth mentioning that currently many ambiguous titles such as green packaging and environmentally friendly packaging create confusion to users and processors without specific definition. These issues have to be defined properly before proper implementation of the concept. The criteria for ranking packaging based on its sustainability are an active area of development: ASTM Committee D-10 on Packaging and the Institute of Packaging Professionals are currently experimenting with a rankings system. General guidance, metrics, checklists and scorecards are being published by several groups. Government standards organizations, consumers, retailers and packagers are considering several types of criteria.

The broad goals of sustainable packaging can be summarized as:

- **Functional:** Product protection and quality retention, safety, regulatory compliance, etc.
- **Cost effectiveness:** Expensive materials should be avoided.
- **Support:** Long-term human and ecological health.
- **Specific factors for sustainable design of packaging may include:** Minimal use of packaging materials, avoid layers in packaging, lower weight, lower volume, etc.

- **Logistics efficiency (through complete life cycle):** cube utilization, tare weight, enablement of efficient transportation, etc.
- **Energy efficiency:** total energy content and usage, use of renewable energy, etc.
- **Recyclability and reuse**: Use recycles materials, recovery value, repeated reuse of package, reuse for other purposes, etc.
- **Use of biodegradable materials:** These materials biodegrade more quickly, creating no hazard for environments or land fillings.
- **Worker impact:** occupational health, safety, cleans technology, etc.

The principle and level of sustainable packaging according to SPA is presented in Table 14.1. and Figure 14.1.

Table 14.1 The principle and levels of sustainable package (James et al., 2005)

Principles	Packaging will support sustainable development if the following principles are met	Levels at which the principle is applied
Effective	It adds real value to society by effectively containing and protecting products as they move through the supply chain and by supporting informed and responsible consumption. It reduces product waste, Improves functionality, Prevents over-packaging, reduces business cost, and Achieves satisfactory return on investment (ROI).	Society
Efficient	Packaging systems are designed to use materials and energy as efficiently as possible throughout the product life cycle. This should include material and energy efficiency in interactions with associated support systems such as storage, transport and handling. Improves product/packaging ratio, Improves efficiency of logistics, Improves energy efficiency (embodied energy), Improves materials efficiency (total amount of material used), Improves water efficiency (embodied water), Increases recycled content, Reduces waste to landfill.	Packaging System
Cyclic	Packaging materials are cycled continuously through natural or (industrial) technical systems, minimizing material degradation and/or the use of upgrading additives. Returnable, Reusable (alternative purpose), Recyclable (technically recyclable and system exists for collection and reprocessing) and Biodegradable	Packaging Material
Safe	Packaging components do not pose any risks to human health or ecosystems. When in doubt the precautionary principle applies. Reduces airborne emissions, Reduces waterborne emissions, Reduces greenhouse gas emissions, Reduces toxicity, Reduces litter impacts	Packaging Component

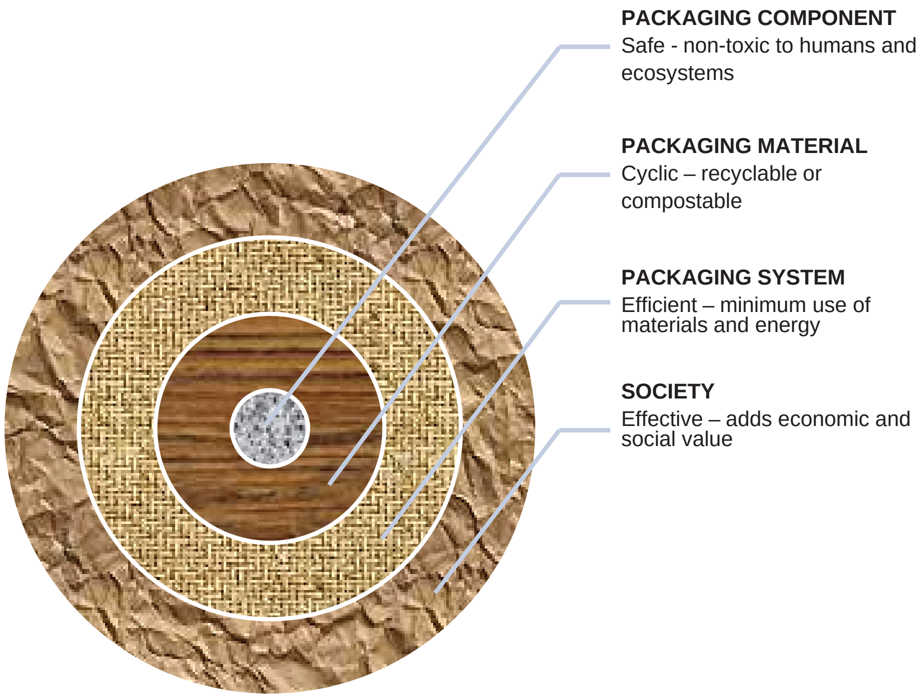

Figure 14.1 The four levels and principles of sustainable packaging (Reference: James et al. 2005).

14.4 Strategies for sustainable packaging

Packaging protects the environmental and economic investment in products and contributes to economic development and social well-being by facilitating the distribution and delivery of products to the marketplace. However, after its useful life, packaging becomes a burden to the society. Creating economically viable, closed loop systems for the recovery of packaging materials is an essential characteristic for sustainable materials management. Such a strategy supports individuals and communities through the creation of gainful employment, development of recovery infrastructure, conservation of resources and measurable improvements in environmental performance.

Based on SPA's working definition of sustainable packaging and four identified principles some of the strategies recommended by Lewis et al. (2010) are presented in Table 14.2.

A comparative evaluation study of three types of bags made from different packaging materials (i.e. single use plastic carry bags, single use paper carry bags and reusable PP carry bags) revealed that any final decision about the most 'sustainable' option needs to be informed by scientific tools (e.g. LCA), but it will ultimately be based on an evaluation of specific requirements

Table 14.2 General strategies and key performance indicators for the design, procurement or evaluation of sustainable packaging (Lewis et al., 2010)

Principles	Strategies for packaging design, manufacture, logistics and marketing	Key performance indicators
Effective: sustainable value: The packaging system achieves its functional requirements and contributes to economic, social and environmental sustainability	Eliminate any packaging which is not necessary Ensure that the packaging fulfils all functional requirements, e.g. product containment, protection, convenience, communication and marketing Identify any potential health or safety risks to consumers and others in the supply chain and take steps to eliminate or reduce these	Functionality of each component of the packaging system Social and economic benefits of the packaging system as a whole
Efficient: minimal use of materials, energy and water The packaging system is designed to use materials and energy efficiently throughout the product life cycle. Efficiency can be defined through reference to world's best practice at each stage of the packaging life cycle	Reduce packaging volume and weight to the minimum required for product protection, safety, hygiene and acceptability to the consumer Increase the efficiency of the product packaging system by changing the product, e.g. use of concentrates Minimize product waste Maximize energy and water efficiency during manufacturing and recovery systems Improve transport efficiency by maximizing cube utilization Improve the efficiency of transport and logistics by redesigning distribution systems	Total weight of material used in the packaging system (primary, secondary, tertiary) Packaging-product ratio by weight Percentage of product which becomes waste before it reaches the consumer Percentage of product remaining in the primary packaging once the product has been dispensed Energy consumed over the packaging lifecycle (MJ per ton of packaging) Water consumed over the packaging lifecycle (kL per tonne of packaging) Pallet configuration and efficiency – cube utilization (%) Truck utilization km travelled

(*continued*)

Table 14.2 (*Continued*)

Principles	Strategies for packaging design, manufacture, logistics and marketing	Key performance indicators
Cyclic: minimizing waste Packaging materials used in the system are cycled continuously through natural or industrial systems, with minimal material degradation. Recovery rates should be optimized to ensure that they achieve energy and greenhouse gas savings.	Identify the cyclic loops which are available to recover the packaging and ensure that the packaging can be collected and processed within them Reusable packaging: design to minimize lifecycle impacts, e.g. by maximizing return rates. Design for 'closed loop' reuse in preference to an alternative use Recyclable packaging: • specify a material with an existing and widespread system for recovery • if possible use only one material, if not use materials which are easy for the consumer to separate or do not contaminate recycling systems • design for 'closed loop' recycling rather than 'downcycling' • use the maximum amount of recycled content which is physically possible (preferably post-consumer) Degradable packaging: specify biodegradable rather than oxo-degradable materials and ensure that a system is available for collection and processing Provide advice to the consumer on correct disposal of the packaging	Collection and reprocessing systems for the packaging Reusability (national recovery rate for the product through company/ industry schemes) Recyclability (national recovery rate for the material through recycling systems) Percentage of the packaging (by weight) which can be recovered through available recycling processes Average % of recycled material (post consumer) Average % of recycled material (total) Compostability (national recovery rate for the product through composting systems) Recycling information and advice on recyclable packaging Instructions NOT to recycle on containers used for hazardous products Number of separable components Percentage of packaging material which is from a renewable source

	Minimize the number of separable components to minimize the risk of a component becoming litter Specify renewable materials where it is demonstrated they provide the lowest environmental impact Use renewable stationary energy Use renewable transport energy (e.g. biofuels) where these are found to have the lowest environmental impact	Percentage of stationary energy use which is from a renewable source Percentage of transport energy which is from a renewable source
Safe: non-polluting and non-toxic Packaging components used in the system, including materials, finishes, inks, pigments and other additives do not pose any risks to humans or ecosystems. When in doubt the precautionary principle applies.	Manufacture packaging using cleaner production techniques and using best practice materials and energy consumption technologies Avoid or minimize the use of heavy metal based additives ($<$100 p.p.m. per packaging unit). Avoid or minimize the use of materials or additives that may migrate into food and be harmful to human health, e.g. certain plasticizers Avoid or minimize the use of materials or additives which may pose risks to humans or ecosystems during recovery or disposal Minimize the environmental impacts of transport, e.g. by using sea freight rather than air freight, and by using clean fuels for road transport	Cleaner product policies and procedures (list) Use of heavy metal-based additives (list) and concentration (p.p.m.). Health or environmental risks associated with the package (list) Mode of transport used for each stage of the packaging life cycle (km) Fuel type used for each stage of the packaging life cycle (list)

(functionality, cost, etc.) and environmental priorities (Lewis et al., 2010). Each bag option provides different levels of functionality and convenience, and has environmental advantages and disadvantages. Furthermore, other important issues need to be considered, including: functionality and cost; and occupational health and safety.

14.5 Advantages of sustainable packaging

The benefits of sustainable packaging according to Ryan (2010) are given below:

1. Reduced packaging minimizes the costs of operation in numerous ways:
   - Material costs are reduced in relation to the volume of components used.
   - The weight and size of packaging is reduced, so are the transportation costs.
2. Social responsibility is the key to the concept. Consumers are demanding honesty and altruism from the companies they solicit. Subtle hints at environmental and community awareness can lead to big increases in customer loyalty and sales.
3. Government initiatives are promising in the sustainability arena. With several new regulations regarding business operations and their impact, it is safe to believe that it is only a matter of time before regulations regarding certain levels of responsible packaging are drafted. Quick off the mark, voluntary adopters will most definitely have an advantage here.

14.6 Packaging types and recyclability

The major categories of materials used for food packaging are glass, metals (aluminum, foils and laminates, tinplate, and tin-free steel), paper and paperboards, and plastics (Ahmed and Alam, 2012). Today's food packages often combine several materials to exploit each material's functional or aesthetic properties. Briefly, a few packaging materials with recycle potentials are discussed below:

Paper
One of the most widely used packaging materials, particularly corrugated fibreboard used for transport packaging, and also the biggest recycling opportunity. The current recycling rate for paper and paper board packaging waste is about 49%.

Glass
Glass is one of the most common forms of packaging wastes. Glass containers offer benefits in that they can be reused numerous times before recycling. A well-coordinated recovery and recycling system exists in most of the developed countries. The annual recycling rate for glass bottles is about

22%. The North American Insulation Manufacturers Association reports that about 300 000 tons of recycled glass annually goes into producing thermal and acoustical insulation.

Aluminum

Aluminum is used in many packaging applications especially beverage cans, foil and laminates. It has a high return value as a scrap metal and can be recycled economically. The current recycling rate for can is about 54%, according to figures from the Aluminum Association, the Can Manufacturers Association and the Institute of Scrap Recycling Industries. Recycling aluminum requires 95% less energy than production from raw materials.

Steel

Steel is a widely used packaging material for food, paint and beverage as well as aerosols. Recycling steel brings significant resource and energy savings. The current recycling rate for steel cans is about 15–20%.

Plastic

Plastic offers several advantages over other packaging materials in its robustness and low weight. Even though plastic can be recycled there is a lack of facilities in many countries. The current recycling rate for plastic is 5–10%, with the remainder either land filled or incinerated.

Mixed materials

Mixed materials packaging can sometimes have the benefits of being more resource and energy efficient than single material packaging, but combining materials makes recycling difficult. Recycling these materials is hindered by the lack of facilities and technology necessary to separate materials to avoid contamination. Mixed materials packaging can be reprocessed into other products such as floor coverings, shoe soles and car mats, incinerated to produce energy, or land filled.

14.7 Life cycle assessment (LCA) and sustainable packaging

The key measurement tool for environmental sustainability is life cycle assessment (LCA). LCA has been started with analysing the life cycle of the pathogen stream at every stage, including monitoring the control strategies (McLeod, 1999). Please consult Chapter 4 for a complete introduction into the concept and implementation of LCA in the food processing industry.

Considering food packaging, an example of life cycle assessment of fruit juice packed in polylactide based nanocomposite film and its distribution is illustrated in Figure 14.2. Four different life cycles are identified to carry out

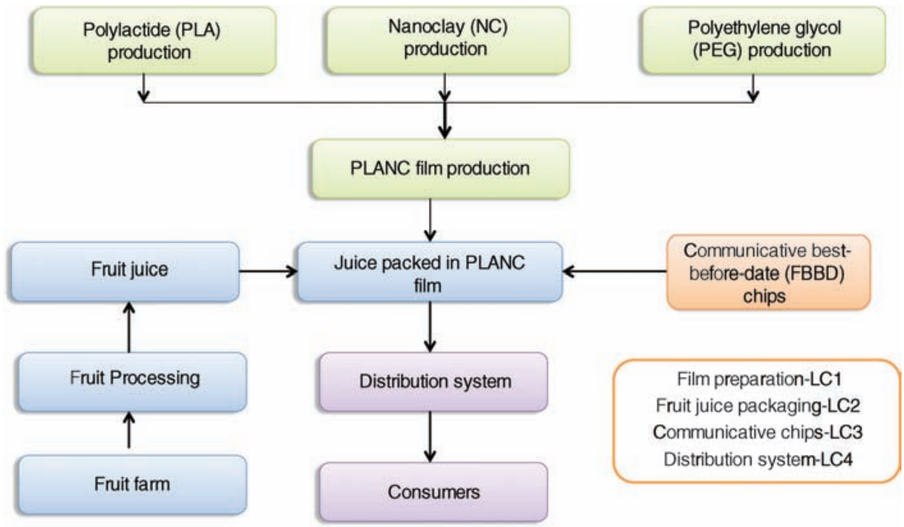

Figure 14.2 Life Cycle Assessment (LCA) flow diagram for fruit juice packed in polylactide based nanopackaging.

the environmental assessment intended within the study: (1) fruit juice life cycle, (2) package life cycle, (3) communicative best-before-date (FBBD) chip life cycle, and (4) life cycle for the distribution system.

There are many studies reported in the literature that used LCA to evaluate packaging used for food products. Keoleian and Spitzley (1999) evaluated seven systems – single-use and refillable glass bottles and HDPE containers, paperboard gable-top cartons, linear low-density polyethylene (LDPE) flexible pouches and polycarbonate refillable bottles – for life cycle, solid waste, energy and costs. The major findings for the containers studied were low fabrication cost, barrier properties comparable to glass, low weight and shatter resistance afforded by plastics, resealability, low material production energy per unit delivered, low material production of solid waste per unit delivered and high end-of-life recyclability. Further, the study concluded that the refillable HDPE and polycarbonate containers and the flexible pouch were the most environmentally preferred packaging systems with respect to life-cycle energy and solid waste.

Dobon et al. (2011) evaluated the environmental assessment of a communicative best-before-date (FBBD) chip in the packaging materials containing pork using a cradle-to-grave approach. Although FBBD communicative device was one of the constituents of the packaging system, its life cycle was dealt with separately in order to assess the relative contribution to environmental impacts due to only FBBD communicative device. Authors observed that the use of a FBBD contributes to minimize environmental burdens related to the production, packaging and delivery of pork chops since

it facilitates a dynamic control of out-of-date products even though the consumer unit with FBBD weighs 1 g more than the consumer unit that does not use the communicative device.

Siracusa et al. (2011) evaluated a cradle-to-grave LCA study of a food packaging envelope made with a multilayer polymer film (Low density polyethylene/Polyamide; LDPE/PA), with two different depths of 70 and 90 μ. The film process production contributed the most environment impact during pellets polymer production, whereas a less percentage was attributed to the film production. So, the possibility of utilizing recycled polymer pellets was taken into consideration.

In order to facilitate the provision and application of LCA information in decision making during packaging design, development and utilization, there is a prima facia case for a 'streamlined' LCA tool, provided it meets a set of requirements, including functionality, accuracy, validity, reliability and usability (Verghese et al., 2010). Packaging Impact Quick Evaluation Tool (PIQET) has been considered as one of the finest LCA components designed to allow for packaging system scenarios to be evaluated. Utilizing embedded life cycle inventory data for material manufacture, converting, filling, cleaning of returnable, transport and end-of-life waste management processes, PIQET presents life cycle environmental impacts for the different levels of packaging (Verghese et al., 2010).

The key activities of PIQET over the period 2004–2007 and the subsequent upgrades to PIQET (2008–2009) have been identified and reported by Verghese et al. (2010). The major activities are given below:

(i) Establishment of Industry Advisory Committee (IAC): In this activity the research team (packaging technologists, environmental managers, food manufacturers and brand owners) should be actively involved with potential users from the beginning of the project.
(ii) Literature review.
(iii) Classification of packaging levels.
(iv) Development of system boundary: The scope of assessment of packaging system boundary in PIQET is 'cradle-to-grave' and includes the following life cycle phases for a packaging component: raw material production, material conversion, transport of packaging material to filler, filling of packaging, transport of packed product to retailer, return transport to filler for returnable packaging, cleaning for returnable packaging and end-of-life waste management (includes landfill, recycling, incineration with energy recovery, incineration without energy recovery and composting).
(v) Development of impact assessment methodology: The Australian impact assessment method developed by CfD has been used in PIQET and presented in Table 14.3.
(vi) Use of SimaPro and MS Excel for proof of concept.

Table 14.3 Life cycle environmental impact indicators reported in PIQET (Adapted from Verghese et al., 2010)

Indicator	Unit	Description
Climate change	kg CO_2 eq	Climate change effects resulting from the emission of CO_2, methane or other gases into the atmosphere- this indicator is represented in CO_2 equivalents. Factors applied to convert greenhouse gas emissions into CO_2 equivalents emissions conform to the 1996 Kyoto Protocol (Houghton et al., 1996). Those factors are still applied in all official reporting on greenhouse gases emissions, despite the implementation of new factors by the IPCC (Solomon et al., 2007).
Cumulative energy demand	MJ LHV	All energy use including fossil, renewable, and nuclear energy are taken into account, including feedstock (energy incorporated into materials such as plastic). The energy indicator has been designed on the basis on the first CML impact assessment method (Heijungs et al., 1992a, b).
Minerals and fuels	MJ surplus	The additional energy required to extract mineral and fossil fuel resources due to depletion of reserves, leaving lower quality reserves behind. The minerals and fossil fuel indicator has been designed from the Eco-Indicator impact assessment method (Goedkoop and Spriensma, 2001).
Photochemical oxidation	kg C_2H_4 eq	Measurement of the increased potential of photochemical smog events due to the chemical reaction between sunlight and specific gases released into the atmosphere. These gases include nitrogen oxides (NOx), volatile organic compounds (VOCs), peroxyacyl nitrates (PANs), aldehydes and ozone. Factors applied to convert emissions into C_2H_4 equivalents are taken from the CML impact assessment method from 2000 (Guinée et al., 2001).
Eutrophication	kg PO_4^{3-} eq	Eutrophication is the release of nutrients (mainly phosphorous and nitrogen) into land and water systems, altering biotopes, and potentially increasing algal growth and causing related toxic effects. Factors applied to convert emissions into PO_4 3^- equivalents are taken from the CML impact assessment method from 2000 (Guinée et al., 2001).
Land use	Ha*a	Total exclusive use of land for a given time for occupation by the built environment, forestry production and agricultural production processes. This indicator is mostly used to have a measure of the impact on biodiversity. Most of the data are similar to the CML impact assessment method from 2000 (Guinée et al., 2001).
Water use	kL H_2O	Total of all water used by the processes considered, except turbine water used in hydro generation of electricity.
Solid waste	kg	Total of all solid waste generated by the processes considered. This indicator has been designed according to the first CML impact assessment method (Heijungs et al., 1992a,b). Note that the CML 92 is the only European impact assessment method that takes solid waste into account.

(vii) Web portal final product: The first web-based version of PIQET was completed in late 2007 using the algorithms developed and road-tested in the MS Excel version of the tool.

14.8 Consideration of package design

Packaging design is one of the important considerations of sustainable packaging. By comparison with traditional packaging design, sustainable packaging design requires a greater focus on innovation to optimize functionality (Lewis et al., 2010). Materials engineering has the potential to assist brands in meeting sustainability targets by light weighting without performance compromise, reducing the complexity of barrier materials and improving the quality (clarity/transparency) of recycled materials. Continuous improvement in the performance of plastics materials and compatibility with established waste-streams will serve to build brand trust amongst global and local brands alike (Pira International, 2011).

Instructions for ensuring sustainable product–package combination design have a great importance. Packaging design often requires difficult trade-offs; for example, efforts to increase packaging recyclability – a typical goal in packaging management – may actually result in other impacts, such as greater overall energy use (CCME, 2009). About 70% of the overall impact of a product is determined in the design phase. Packaging design has to be considered to meet critical cost, performance, marketing and regulatory requirements. Sustainable design for packaging starts with informed material selection, a clear understanding of performance requirements and also consideration of life cycle. These include: energy use over the life of the package, impact of materials in all end-of-life scenarios, and appropriateness of the package design to facilitate material recovery. Other factors that should be considered in the design phase are consumer behaviour and the variation of established recovery systems by market. Some non-environmental issues like product quality retention, health and safety standards, laws and regulations have to be taken care of in packaging design while evaluating for packaging sustainability. Several methodologies are currently used to support sustainable design including design for environment strategies like design for recycling and source reduction.

Various tools have been formulated to help packaging designers to promote greener or more sustainable package design. Guidelines about packaging are given in national laws and EU directives, as well as in regulations set by the CEN Standards 13427–13432 about packaging and packaging waste. In 2013, there will also be the ISO packaging and the environment standards 18601–18606. In addition, there are several design guidelines and analytical methodologies that emphasize different aspects of sustainability as presented (Grönman et al., 2012).

Svanes et al. (2010) described a holistic methodology for designing sustainable food packaging. Authors advocated that the following main categories should be evaluated over the whole life cycle and distribution chain for the design:

1. Environmental performance of the total packaging/product system.
2. Total distribution costs of the packed product. This includes, for example, cost of all materials and processes along the distribution chain such as packaging, packing process, storage, transport and retail costs.
3. Preservation of product quality.
4. Market acceptance, branding and exposure.
5. User friendliness.

Further, Svanes et al. (2010) considered a number of indicators in their methodology of sustainable food package design. Six different indicators have been identified in their methodology related to environmental and resource impacts. These indicators are briefly discussed below:

Gross material intensity (GMI)
GMI indicates total mass of packaging materials used in the total packaging system. This parameter takes reuse into account, and it carries more product, but without the initial burdens of production of the raw materials and packaging. This parameter indicates the total burden caused by material usage.

Net material intensity (NMI)
NMI measures the mass of packaging materials that is not being recycled. NMI simply provides an estimate for the total amount of packaging waste generated from the systems.

Degree of filling
Degree of filling measures the efficiency of the packaging system with respect to transport work. This parameter is a very good indicator of transport efficiency.

Cumulative primary energy use
Cumulative primary energy use over the total life cycle and distribution chain of the packaging system is measured as total use of primary energy. Important contributors to total energy consumption are a production of packaging and its raw materials, the packing process, transport and storage in refrigerators or freezers.

Greenhouse gas emissions
Greenhouse gas emissions over the total life cycle and distribution chain of the packaging system, measured in CO_2-equivalents.

Amount of product waste

The amount of product waste generated from the whole distribution chain is measured in mass of product loss. Impacts from treatment of waste are accounted for in the indicators, for example, energy recovered in incineration of used packaging or emissions from land filling.

14.9 Effect of design on sustainability

Life-cycle inventory (LCI) is another term used for packaging sustainability which measures material use, energy use, environmental discharges and wastes associated with each stage of a product system over its life cycle, from raw material extraction to material processing, product fabrication, use, reuse or recycling and ultimate disposal (ISO, 2006). Singh et al. (2011) studied the effect of the environmental impacts associated with the packaging design/systems for three types of 3.79 l (1 gallon) high-density polyethylene (HDPE) plastic milk containers available in the US retail market using the LCI analysis. Two of the primary container types (original, cube and stackable) studied use reusable plastic crates (RPCs) for stacking and shipping, while the third one is a heavy duty container that does not require secondary shipping containers. The study indicated that the use of RPCs for controlled environment distribution reduces the material requirements of the primary containers resulting in a reduction of the overall CO_2 emissions. The study concludes that transportation weight limits must be considered as a limiting factor in package design for liquid products, as trailers 'weigh out' before they 'cube out'. As related to the LCI impacts, this study found that the original and cube container-based packaging systems have better overall per functional unit performance in comparison with the stackable design.

14.10 Environmental impact of packaging and food losses in a life cycle

Perishable foods are processed and packed in suitable packaging materials to enhance the shelf-life of the finished products and easy transportation/distribution across the globe. Efficient packaging is one way to decrease food losses and to reduce the environmental impact of the food distribution chain (Sonesson and Davis, 2005; Marsh and Bugusu, 2007). However, sometimes the packaging itself is the reason for food wastage. Packaging can be difficult to remove from the food especially sticky and fatty foods and thereby losses can be caused. The average amount of product left in some tested packaging was 3–10%, when the packaging was considered emptied by the consumer (Johansson, 2002). Among processed products, beef and related products, followed by dairy products, generate the greatest environmental impact (Tukker and Jansen, 2006). The causes of these losses can be biological

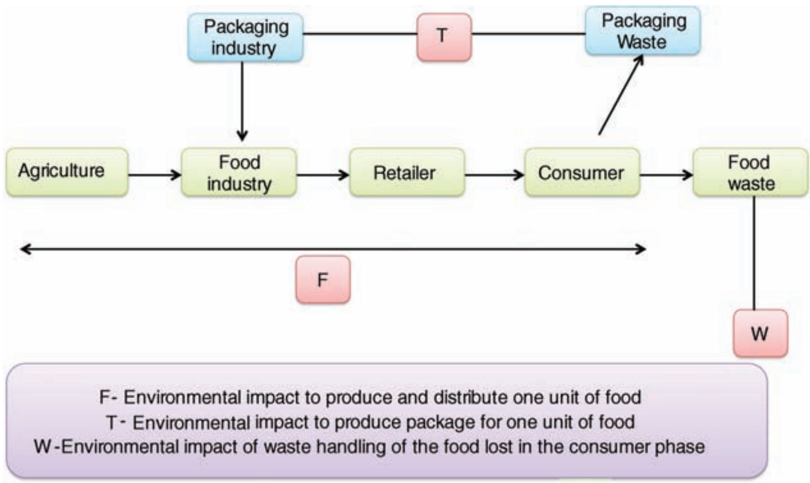

Figure 14.3 Schematic illustration of the food supply.

and environmental (e.g., respiration, ethylene production, water stress, temperature, humidity, atmospheric composition) or socioeconomic (e.g., insufficient marketing, communication, distribution and legislation) (Kader, 2005). The measures taken to decrease food losses may play a significant role in reducing the overall environmental impact (Johansson, 2002; Eide, 2002). The total change in environmental impact from the packaging and from the food losses should then be considered in order to identify potentials for packaging development.

Williams and Wikström (2011) recently evaluated the environmental impact of packaging and food losses during a cycle starting from the field to fork and the balance between the two for five different food items. An illustration based on their studies is presented in Figure 14.3 where T is the environmental impact of the packaging production and packaging waste handling per unit of purchased food; F is the energy use or environmental impact to produce and distribute one unit of purchased food to the consumer, with the exception of the packaging, and W is the energy use or environmental impact of waste handling of the food lost in the consumer phase. The environmental impact categories considered here are energy use, global warming potential (GWP), eutrophication potential (EP) and acidification potential (AP). Table 14.4 represents the calculated data for the subsystems, F, and packaging, T, for the selected food items (ketchup, bread, milk, cheese and beef) and for the different environmental categories. Results revealed that packaging that reduces food waste can be an important tool to reduce the total environmental impact, even if there is an increase in impact from the packaging itself. Food materials like cheese exhibited high environmental impacts. The potential is low for food items with a low ratio

Table 14.4 The environmental impact from food, F, and environmental impact from packaging, T, and the ratio F/T (Reference: Williams and Wikström, 2011)

Impact	Unit	Ketchup	Bread	Milk	Cheese	Beef
F (Energy)	MJ/kg of food	11	7.8	4.6	38	48
T (Energy)	MJ/kg of food	5.7	0.77	0.64	0.65	3.1
F/T (Energy)		**1.9**	**10**	**7.2**	**58**	**15**
F (GWP)	g CO_2-equiv./kg of food	790	610	950	8500	14000
T (GWP)	g CO_2-equiv./kg of food	260	28	65	44	150
F/T (GWP)		**3.0**	**22**	**15**	**190**	**90**
F (EP)	g O_2/kg of food	64	99	224	2100	4300
T (EP)	g O_2/kg of food	2.9	0.96	1.8	1.8	7.0
F/T (EP)		**22**	**100**	**120**	**1200**	**610**
F (AP)	mol H^+/kg of food	0.20	0.096	0.45	4.0	8.8
T (AP)	mol H^+/kg of food	0.004	0.0063	0.0059	0.0088	0.05
F/T (AP)		**50**	**15**	**7**	**450**	**180**

between the impact of food and the impact of packaging. Ketchup is the best example for the study.

14.11 Concern of safety and health hazard during sustainable packaging life cycle

Human and ecological health is a basic requirement of sustainable development. Material characteristics are an important critical point which provides information about the presence and release of harmful substances to the environment. Related to clean production, material health extends consideration of the use and emission of substances of concern through the use and end of life phases of packaging (Vollenbroek, 2002). It is recommended to identify and minimize or eliminate hazards associated with materials used in packaging along the life cycle. The accumulation of problematic substances in the biosphere and in our bodies is the subject of increasing concern for consumers, health professionals, governments and industries. Packaging may use or contain certain chemicals that result in the unintended release of harmful substances during the life cycle of the package. The presence of even trace amount of chemicals like bisphenol A, melamine or polyvinyl chloride in products or packaging are the safety concern. Ensuring all ingredients including additives, inks, adhesives and coatings are safe for human and environmental health throughout their life cycle is a vital aspect of sustainable packaging design. Careful selection and specification of the safest materials available to meet the package performance requirements is the preferred strategy. All companies should track legislation, material bans, and substances of concern to identify compliance issues and minimize risk. Leading companies have clear restricted substance lists and are identifying alternatives for

substances of concern in order to design out hazards where possible and take packaging design beyond compliance towards sustainability. There is also a need for greater transparency regarding used chemicals or materials used in packaging and to encourage the optimization of material formulations for human and environmental health. The development of tools and methodologies to assess material health is ongoing and will allow more transparent communication of material characteristics throughout the value chain.

14.12 Global legislative guidelines of sustainability

Packaging becomes a concern after delivering the food to the consumer. The quantity of packaging in the waste stream, its visibility and the overall reduction in capacity to effectively manage such wastes has resulted in action directed at reducing the impact of packaging and packaging waste on resources and the environment (Sinclair, 2000). Most countries require manufacturers to take responsibility for their packaging and participate in collection schemes or product stewardship programmes (SAP, 2011). For global players, precise recycling reporting in each country is a real challenge.

Sustainability initiatives led by global legislation, retailers and corporations guide package material choices, design, and food packaging sales for food packaging professionals. The revised 1997 European Commission's Packaging and Packaging Waste Directive, the 2007 REACH (Registration, Evaluation, and Authorization of Chemicals), and the BS EN 13432 standard (which defines compost-ability, degradability and biodegradability) are examples of effective global legislative guides in a majority of the Group of 8 countries (Canada, France, Germany, Italy, Japan, Russia, United Kingdom, United States and the European Union), BRIC (Brazil, Russia, India and China), and the developing world. United Kingdom retailers have been long-term promoters of sustainable packaging and have launched impressive initiatives such as Marks and Spencer. Wal-Mart, the world's largest retailer set an example on sustainable packaging. The company set up the Sustainability Consortium to collaborate with suppliers, retailers, non-governmental organizations (NGOs) and government officials to conduct research and develop data and tools that will enable research-driven product sustainability measurement and reporting. The Consortium will help develop a global database of information on products' life cycles – from raw materials to disposal (Wal-Mart, 2012).

14.13 Conclusions

Sustainable Packaging system is a complex concept leading to the reduction of the burden of waste by intelligent design of packaging materials. The concept

is highly appreciated and welcomed by industries. Currently, a more holistic approach has been accepted to meet the demand of sustainable packaging. In conjunction with defining sustainability, SPA has recognized the need to translate the complexity of sustainable development, environmental regulations and complex environmental assessment protocols/models, such as LCA, into practical tools for the diversity of skills and functions involved in packaging sustainability. In addition to packaging, type of food materials also plays a significant role in the food packaging sustainability. The multi-criteria packaging evaluation and assessment tools have environmental impact with functional and commercial performance and their environmental performance in conjunction with the technical, commercial, social and regulatory context of the sustainable packaging system.

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15 Sustainable Cleaning and Sanitation in the Food Industry

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15.1 Introduction

Food soil represents any unwanted material on the surfaces of food processing plant, with the primary source of this soil is the food product often being processed. Soil can be deposited on equipment to form films that negatively interact with the processing integrity, for example, on the walls of an empty tank or internal surface of a heat exchanger. Such films can also be formed out of deposited water minerals and cleaning compounds as well as microbiologically active residues (i.e. biofilms), all of which can contribute to the soil build-up. The resulting complex aggregations of materials enhance survival and growth of microorganisms, and when formed are very difficult to remove.

Cleaning is the removal of soil from food contact surfaces to ensure that they are (1) visually clean (without signs of oxidation), (2) are not malodorous and (3) are not greasy to touch. Sanitization on the other hand is making sure a clean surface is substantially free from pathogenic microorganisms and an undesirable quantity of spoilage microorganisms (Marriott and Gravani, 2006). Therefore, the cleaning and sanitation procedures used in the food industry must actively destroy vegetative cells of hazardous microorganisms as well as substantially reducing numbers of other undesirable microorganisms

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without adversely affecting the product quality or its safety for the consumer (Pan et al., 2006). The interest in having highly effective cleaning and sanitation programmes is not solely a case of maintaining public responsibility but it is also inherent in international food law and regulations as food business operators must implement and maintain hygiene procedures based on HACCP principles as part of EU Regulation 852/2004 (Article 5).

In order to develop economically and environmentally sustainable cleaning and sanitation programmes food processors must consider a wide range of different influencing factors. These range from the surface in contact with the food, the process temperature, and the sanitizing agent on the effectiveness of the cleaning system. Therefore, the development of cleaning protocols requires significant knowledge of the underlying physiochemical phenomena in order to ensure a sustainable use of chemicals, energy and water during the process. Over the years, two types of cleaning and sanitation strategies have emerged, namely cleaning out of place (COP) and cleaning in place (CIP), with CIP proving to be the most economical approach, especially for liquid based food processing. Cleaning in place (CIP) is now a widely incorporated approach to cleaning for almost all dairy, beverage and processed-food production units.

The sustainability of the cleaning process not only depends on the type of cleaning strategy, but also on the characteristics of the cleaning agent which must be given serious consideration for each type of application. In many cleaning applications in the food industry physiochemical alteration mechanisms are utilized, whereby the cleaning agent physically interacts with soil through wetting, softening (plasticizing), swelling, heating, and so on. A chemical reaction such as saponification of lipids, hydrolysis of proteins and decomposition of salts, alter the structure of the soil. The most commonly used detergents are dilute NaOH and dilute acids. In addition, fluid flow is often the only means of developing enough shear-stress to dislodge the bound soil and subsequently transport it and micro-organisms out of the system to avoid contamination of already cleaned surfaces. All the above issues need to be taken into account during cleaning procedures in the food industry. The effectiveness of surface sanitizers is also extremely important as they must have a high microbial destruction capability against a wide range of microorganisms.

Chemical sanitation methods are economical and chemicals such as chlorine have found widespread use throughout the food industry due to its ability to inactivate all types of vegetative cells. Chlorine is a germicide that acts on the membranes of microbes to inhibit the enzymes involved in glucose metabolism and oxidize protein within the cell. Chlorine is activated at low temperature, and is economical, leaving small amounts of residue on surfaces. However, major disadvantages are also associated with chlorine by-products, such as they are corrosive to many metal surfaces (especially at higher temperatures), they can cause health and safety issues due to skin irritation and mucous membrane damage in confined areas. Moreover, under certain

conditions chlorine can form potentially carcinogenic trihalomethanes (THMs). Although there are hazards associated with the formation of carcinogenic from chlorine are of public concern there are not many other suitable chemical sanitizers commercially available with such a wide range of microbial action. Therefore, over the years, the search for new sustainable sanitizers has become more widespread with alternative powerful but environmentally-friendly oxidizing compounds like ozone being given due consideration as a potential alternative to chlorine.

The aim of the current chapter is to look at the issues specific to the sustainability of cleaning and sanitization in the food industry. The basic considerations of designing a sustainable cleaning and sanitation programme will be outlined followed by the current state of the art CIP cleaning strategies. Ozone will then be considered as an exemplar of emerging environmentally sustainable cleaning technology for use as part of a cleaning regime in the food industry.

15.2 Developing an effective and sustainable cleaning programme

In the design of a cleaning and sanitation programme, significant understanding is required with respect to the equipment to be cleaned and the cleaning standards to be complied with. As the food will often be directly consumed after processing, a paramount consideration in the planning of any cleaning programme must be food safety, owing to the potential for *Salmonella* spp., *Listeria* spp. and *Yersinia* spp. contamination in the finished product. This accentuates the need for tight food hazard assessment making it essential for a cleaning programme be designed to accomplish this main objective in both an economically and environmentally sustainable fashion. A sustainable cleaning and sanitation programme, must address the following issues (elements of both CIP and COP included):

Sustainability Pillar 1-Society: public safety

1. Microorganisms can grow on almost any surface so it is important to identify all food contact surfaces paying particular attention to low pressure zones where contaminant build-up is high.
2. Identify high heat and moisture zones in the factories, that is, areas where micro-organism build-up can have a significant impact, particularly in zones where condensation is evident.
3. Ensure that high quality water and disinfectant/sanitization protocols are used during the cleaning process.
4. Regularly swab the surface of the processing plant equipment to check the quality of the sanitation programme when it is required.

Sustainability Pillar 2-Economics: efficient cleaning operations

1. Schedule the cleaning to happen alongside maintenance routine to ensure that any equipment taken apart for maintenance can be cleaned simultaneously.
2. Train and incentivise staff to clean-as-they-go in order to reduce build-up, clean-up time and potential pest infestations.
3. Ensure the cleaning procedure efficiently balances the cleaning action due to temperature, detergent and mechanical force.

Sustainability Pillar 3-Environment: optimize use of sanitizers and minimize wastage

1. Try to use programmes that have a reduced environmental load.
2. Ensure all waste material disposal routes are short and direct.
3. To reduce contamination or spills and ensure notices are visible to advise where maintenance activities are on-going.
4. Staff must be trained adequately to ensure they understand chemical usage policies in order to minimize occurrences of accidental food contamination.
5. Ensure equipment is designed so that an optimal balance is easily found between all the cleaning mechanisms.

15.3 Cleaning in place

Cleaning-In-Place (CIP) is generally accepted as being the best approach for cleaning closed systems in the food industry. Closed systems include the food processing equipment with integrated pipes, pumps, valves and tanks, through which liquid food almost continuously flows. To ensure that the cleaning process is cost effective and efficient and therefore sustainable it is essential to optimize all the total energy usage throughout CIP. The total energy input into a process can be summarized by means of the Sinners diagram (Jensen and Friis, 2007) which illustrates the main parameters that need to be applied at different magnitude (Figure 15.1). The basic message behind this diagram is

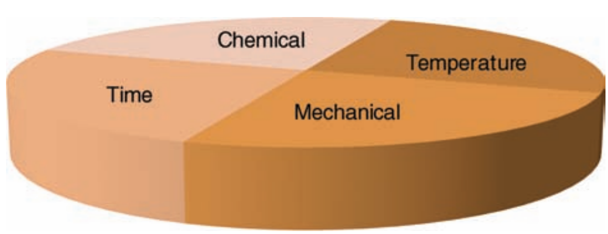

Figure 15.1 Sinner's circle illustrating the energy required to remove soil from a surface with contribution from time, temperature (temp.), detergent (chem.), and mechanical force (mech.) (Jensen and Friis, 2007. Reproduced with permission of Taylor & Francis Group).

that the total amount of energy put into a specific cleaning process always remains the same, meaning that a reduction in magnitude of one parameter has to be compensated by an increase in one or more of the other parameters.

The efficacy of cleaning in a closed system is a function of flow velocity field and the consequent wall shear stress, with this quantity giving mechanical removal abilities of fluid flow (Tsai, 2005; Hall-Stoodley and Stoodley, 2002; Purevdorj-Gage et al., 2006). As the hydrodynamics of the fluid govern the magnitude of shear forces acting on a developing biofilm, it significantly influences much biofilm development (Vieira et al., 1993). Generally in the food industry, the design of processing equipment and pipework tanks is complex and hydrodynamics of the cleaning fluid varies due to bends joints and so on (Blel et al., 2007).

Cracks, crevices, gaskets, valves and joints are the typical points for biofilm formation in food processing equipment. Wall shear stress can be generally calculated using the volumetric flow rate, which might be reasonable for straight piped systems; however this is not suitable for systems where the piping network is complicated. In that case an averaged wall stress can yield incorrect results and therefore biofilm build-up can occur (PathogenCombat, 2010). Having an ineffective CIP process obviously reduces the sustainability of the process from many points of view; public health can be compromised, chemical inputs are not used effectively and direct energy inputs for pumping and heating the cleaning agent are ineffectively used.

A recent EU project PathogenCombat which finished in 2010 looked into the efficiency and effectiveness of CIP programmes in the food industry (PathogenCombat, 2010; Braun and Hadwiger, 2011). During this project large amount of visits to food processing facilities across Europe were conducted where it was found that over 80% of new, CE-marked, food process equipment did not comply with the hygiene provisions of the Machinery Directive released before 2000. They found that regulators and machine suppliers accepted the number and magnitude of hygiene risks associated with the no public safety occurrences which had previously been reported. The project found that significantly more attention must be given to the design, operation and maintenance of CIP equipment in order to obtain a good hygiene standard.

During PathogenCombat engineers focused on the influence of system design, for example, complexity of the piping geometry, junctions positioning, as well as of the fluid flow on each parameter governing cleaning efficiency using fluid dynamical techniques. This approach enabled energy efficient and overall sustainable CIP procedures to be developed for food processing equipment. Jensen and Friis (2007) give the following reasons for how hydrodynamic effects affected the parameters included in Sinners diagram (Figure 15.2):

1. Temperature and detergent: Flow is the most effective method to distribute temperature and detergent (heat and mass transfer by convection) throughout the equipment to be cleaned.

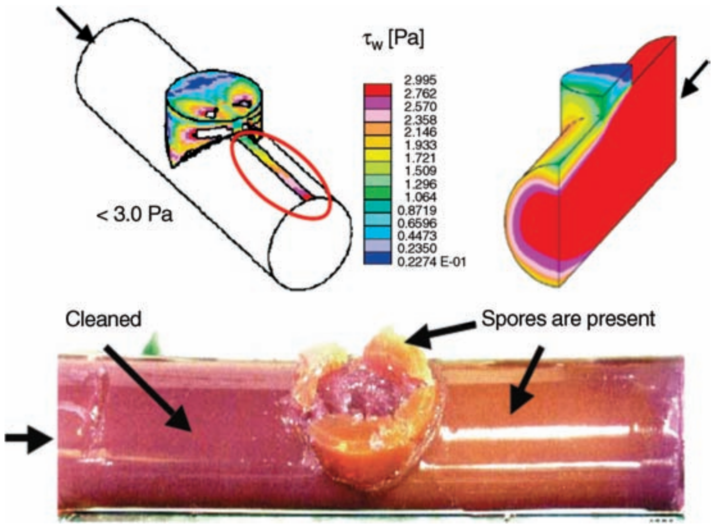

Figure 15.2 Results from cleaning of a T-piece that was carried out during the PathogenCombat project (PathogenCombat, 2010). Modelling results of predicted wall shear stress are shown in the top left and right corners with the experimental evidence in the figure below. In this experiment the orange agar depicts uncleaned zones whereas the purple agar represents the clean areas. (Pathogen Combat, www.pathogencombat.com)

2. Mechanical force: This occurs as a direct influence of the flow, because of the force dragging the soil away from the surface (wall shear stress).
3. Time: Closely linked to the convection of temperature and detergent and hydrodynamic forces, the important aspect of the time is the contact time at the expected at the required temperature and concentration.

Instead of using the term mechanical action alone, hydrodynamics is the appropriate term to use regarding cleaning rate and microbial removal. The hydrodynamic effect is determined by a combination of flow velocity, wall shear stress, fluid exchange, fluctuations and disturbances. The action of fluid flow at process surfaces plays a central role in detaching bacteria and other soil constituents as the shear stress must exceed adhesion and cohesion forces of different soils in order to facilitate cleaning.

By investigating the influence of fluid flow on these parameters Friis and Jensen (2007) showed that local fluctuations in the wall shear stress can improve cleanability particularly where sudden and gradual pipe diameter changes occur; with the best cleaning being obtained when the mean wall shear stress was either above a pre-defined threshold or local fluctuations in wall shear stress. They also found that increasing the pumping speed is not a good

way to improve cleaning as this acts to accentuate the difference between the high velocity and low velocity regions of the flow – thereby reducing the shear stress in places where it is required. It was advised that transient flow or pulsating flow was introduced since this enhanced mass transfer is due to increasing local velocity gradients at the wall, thereby improving the cleaning in problematic zones when compared to a steady state turbulent flow (PathogenCombat, 2010). It was even found that with pulsations at a relatively low flow velocity resulted in good cleaning efficiency, highlighting both the economic and environmental benefits that can be derived from this approach.

15.3.1 Detergents: ozone as a 'sustainable' sanitizing agent

Cleaning operations consume significant amounts of time and energy and can have a negative impact on the environment because of the potential high volumes of pollution in the wastewaters generated by them (Pascual et al., 2007). Therefore, the development of effective and environmentally-sustainable cleaning and sanitizing operations is desirable for the food industry. In this respect, ozone is currently being seen as an innovative technology to meet all of these challenges. The bactericidal properties of ozone are mainly due to it being an unstable allotrope of oxygen therefore it has a special advantage as a sanitizer due to its rapid inactivation power and lower overall energy consumption. For this reason it has been taken into consideration as a replacement for chlorine in the antimicrobial sanitization of water, food, and food processing surfaces and equipment. In practical use, ozone decomposes to a number of free radicals, which attack organic compounds indiscriminately, leaving no residual components when decomposition is complete, while at the same time liberating oxygen. Applications of ozone as a sanitization technology also could include the sterilization of surfaces of contaminated rooms, biosafety cabinets, or entire buildings.

As mentioned above ozone owes its excellent bactericidal, viricidal and sporicidal activities to its powerful oxidizing properties. In sanitization procedures within the food industry ozone is generally used in an aqueous solution, in which it has a higher oxidation reduction potential (ORP) than the form of chlorine used in aqueous solutions, that is, +2.07 volts for ozone versus +1.49 volts for chlorine. It is also reported to be 3000 times as germicidal as chlorine, and retains this strong oxidizing capability in aqueous solution, a property crucial for water disinfection and sterilization. On the other hand, when, considering the use of ozone in sanitization procedures in the food industry, many organic components of food can react with ozone, resulting in self-depletion of ozone and reduced biocidal effectiveness (Khadre et al., 2001). This means that, due to the strong oxidizing power of ozone, the ORP values can be below that expected and even negative

(reducing) values can occur. Therefore, in order to ensure the effectiveness of ozone application, detection technology that works well at the limit of approved concentrations for cleaning and sanitization operations must be used. Of greatest significance to the efficacy of the ozone sanitization procedure are variables such as temperature, pH and quantity of organic matter. As regards temperature, it is widely accepted that the rate of destruction of microorganisms increases as temperature increases. However, when ozone is used as a sanitizer, an increase in temperature leads to ozone becoming less soluble and less stable. So, there is a threshold value of temperature at which ozonation is at its most efficacious; this is significantly less than typical sanitation temperatures. On the other hand, in some cases the increase in ozone reactivity can compensate for the decrease in its stability when the medium temperature is increased. As regards pH, ozone is more stable at low pH values, but at higher pH ozone decomposes with the radicals produced enhancing its efficacy. Therefore, the actual pH that is required should be conditioned by the target microorganism (Kadhre et al., 2001). Finally, organic substances that occur within the ozone aqueous medium may compete with microorganisms for ozone and the efficacy of the ozone sanitizing process will be reduced. Clean water without organic matter is only desirable for use in the sanitization of food processing equipment.

The elimination of bacteria and viruses through ozonation should prove as effective in air as it does in water. While ozone does not generally react with water or air, under ultraviolet irradiation ozone reacts rapidly with water and decomposes into various short-lived radicals, such as the highly reactive hydroxyl radical. Theoretical and empirical evidence suggests that most of the sterilization effect results from the radicals produced, and not the ozone itself (Beltran, 1995). The decomposition reaction can be enhanced in air by the use of ultraviolet irradiation and through controlled humidity. Theoretically, therefore, the effects of ozone in air, under controlled conditions, should parallel the effects of ozone in water, and the effectiveness of ozone for eliminating airborne pathogens in either medium may be comparable. The threshold concentrations at which ozone inactivates viruses and bacteria in water are remarkably low. For example, the threshold for Escherichia coli lies between 0.1 and 0.2 ppm (Broadwater et al., 1973). Viruses are also sensitive to low levels of ozone, an advantage for an air-based system, since these small microbes are especially difficult to remove by filtration.

While ozone has a wide antimicrobial spectrum, its effectiveness is a function of the target microorganism. For example in the case of bacteria, while results are varied in the literature, it can be assumed that gram-negative bacteria are more sensitive to ozonation than gram-positive bacteria and that ozone is more effective against vegetative bacterial cells than bacterial and fungal spores. (Kadhre et al., 2001). In another study Lagrange et al., (2004)

found that ozonated water was not effective in disinfecting food contact surfaces in the presence of protein properties, these can be inactivated by the presence of proteins and consequently recommended efficient cleaning before using ozonated water for disinfection purposes.

15.4 Health and safety issues

At low concentrations, ozone (~0.1 mg/L) can cause irritation to the nose, throat and eyes, and an hour's exposure to ozone concentrations of 2, 4, 15 and 95 mg/L induces symptomatic, irritant, toxic and irreversible lethal effects, respectively, in humans (Khadre et al., 2001). Given that health and safety are of prime importance for the practical application of ozone in food-surface sanitization procedures, it is necessary for the processor to have some means of detecting and destructing ozone in the plant. For example, in gas applications of ozone, ultraviolet analyser equipment can be installed in ozonation rooms and they must trigger both a displayed and acoustic warning signal as soon as the ozone content in the ambient air exceeds 0.1 ppm (Kahdre et al., 2001). Moreover, there should be plans for remedial action in case of accidents, and response procedures for accidental ozone inhalation and training of personnel covering the nature and dangers of ozone, precautions and first aid for ozone inhalation.

15.5 Using ozone in industrial cleaning procedures

Ozone can be used as a sanitizer in both gaseous and aqueous form. As the usage of ozone in gaseous form, studies on its efficiency and effectiveness in disinfecting stainless steel surfaces have been reported in the literature. Moore et al. (2000) found that ozone applications were less successful when dried biofilms were present on the food contact surface. The authors concluded that ozone may prove more effective, therefore, in disinfecting product contact surfaces, which should typically be cleaned several times a day, rather than environmental surfaces, such as walls, which could be cleaned only once a week. Kowalski et al. (1998) found that a high level of bacterial sterilization was possible with airborne ozone. They found inactivation levels had strong parallels with the ozonation in an aqueous medium. Another way of cleaning food processing equipment is by spraying ozonated water directly on floors, drains, walls, wet equipment, tanks (externally or internally) and clean rooms via a mobile or centralized system with handheld, drop-down or low pressure sprayers. Such systems are especially suitable for the equipment cleaning-out-of-place and ozonated cleaning systems have been used this way for the dairy industry (Greene, 1999), and the fresh produce industry with very successful results.

However, the main benefits of ozonation emerge when used as part of a CIP system. As explained above the 'clean-in-place' or CIP system is an automatically operated cleaning system that delivers a number of wash and rinse cycles to the internal surfaces of processing equipment largely eliminate human contact with cleaning agents. Ozonated water can be used in CIP systems by directly injecting it into a facility's fluid distribution network and circulating it for a set duration of time.

The advantages of using ozone in CIP systems, compared to traditional disinfectants, are that it leaves no residues and is applied in cold water. As discussed above, there is an upper limit in the temperature which the cleaning water can attain due to ozone in order to maintain a balance in stability solubility and disinfection power. Moreover, unlike chlorine sanitization, no residues are left, and consequently multiple rinses, which are standard practise in industry, are not needed to remove product residues. The quantity of water consumed can theoretically be less when ozone is employed with reduced risk due to residue formation on the food-contact surfaces. Moreover by using a low-temperature water medium the operating costs of such a system are much reduced with minimum energy consumption. Also, the expansion and contraction of welds on the processing line will not occur therefore preventing untimely deterioration.

Ozone is an unstable gas and readily reacts with organic substances. It sanitizes by interacting with microbial membranes and denaturing metabolic enzymes. It does not leave a chemical residue, and under ambient conditions, it has a half-life of 10 to 20 minutes. Ozone must be electrically generated on-demand and cannot be stored for later use. Once a surface is spray-washed, the microorganisms physically lifted from the surface will be killed as they are conveyed to a drain. Moreover, because ozone requires no storage or special handling or mixing considerations, it may be viewed as advantageous over other chemical sanitizers.

Another major attribute of ozone sanitization is the reduced quantity of chemicals which are discharged into sewer systems together with large amounts of water necessary to rinse out residual chemicals from the machines. Pascaul et al. (2007) reported that in typical cleaning and disinfection practices wastewaters contain soluble organic material, Fats Oils and Grease (FOG), Soluble Solids (SS), Nitrates, Ammonia and Phosphates from product remnants and removed deposit soil, as well as residues of cleaning agents, for example, acid or alkali solutions the wastewater may have a high or low pH and high conductivity. According to Pascaul (2007) replacing chemical products with ozone lowers the concentration of salts and, therefore, the electrical conductivity of discharges. The use of ozone can save water in comparison to other biocides, as it does not leave residues or require a final rinse to remove any residual disinfectant that might remain. Also, ozonated water, which has been used for disinfection, can potentially be re-used for the initial cleaning stages.

15.6 Ozone applications in food processing

The importance of maintaining a sterile and clean environment in the food industry is paramount. A major concern with the contamination of a finished product is that human pathogens such as *E. Coli* and *Listeria monocytogenes* may prevail. Ozone can replace chlorine for sanitizing dairy processing equipment (Dosti et al., 2005). Ozone has been reported to be effective against several milk spoilage bacteria adhered in milk films on stainless (Greene et al., 1993). Bacterial biofilms are a common problem in dairy processing plants and ozone is very effective in producing a good biocidal action on such biofilms (Videla et al., 1995). In a study Greene et al. (1993) observed that the ozone was as effective as chlorine against dairy surface attached bacteria as both treatments reduced bacterial populations by 99%. Apart from being a good sanitizing agent, ozone is also less corrosive compared to chlorine. Guzel-Seydim et al. (2000) studied the use of ozonated water as a pre-rinse technique in dairy equipment by soiling stainless steel coupons and then treating with ozonated water as a pre-rinse. The authors found that the ozonated water (10 °C) removed 84% of dairy soil when compared to warm water (40 °C) treated samples which removed 51%. Scanning electron microscopy pictures further validated their results and it was therefore concluded that when ozone is used in the pre-rinse stage decreased detergent use in the cleaning solution recirculation step may be achievable.

In the case of the wine industry and brewing, cross contamination between batches of wine is a major concern and so is the management of the active yeast. The yeast is a major ingredient in the fermentation process and without it the fermentation process would not occur. During the aging process, *Brettanomyces*, which is a non-spore forming genus of yeast in the family *Saccharomycetaceae* can contaminate the finished wine product and give it undesired off-flavours. Similarly, in brewing problems may be caused by wild yeasts, such as *Candida*, *Brettanomyces* and *Zygosaccharomyces*, which cause the beer to become turbid, ropey or develop a yeasty aroma. Cantacuzene et al. (2002) found ozone very effective at removing *Brettanomyces* from wine barrels. Moreover, due to the ability of ozonated water to disinfect oak barrels, thereby removing the threat of *Brettanomyces*, this technology is now being used on an industrial scale in Australia as an alternative to chlorine. The ozone containing water can be used for bottle rinsing and at various CIP locations throughout the plant such as final rinsing of stainless steel fermentation tanks (Porter, 2002). A recent study has looked into the beer line sanitization at retail outlets such as pubs, bars and hotels as contamination of beer lines occurs as beer contaminated with low levels of bacteria and yeast passes over the tubing surfaces as a drink is dispensed (Fielding et al., 2007). Ozone can be used as a cleaning and sanitizing agent for multiple purposes such as barrel cleaning and sanitation, tank cleaning and sanitation, cleaning-in-place systems, and for

general purpose sanitation in winery (Rice, 2001). Sanitation with ozonated water also tended to be much faster because contact time is reduced and washing is not necessary. The authors also noted that, for health and safety reasons, a CIP system with ozone must be carefully implemented with particular attention being paid to recommended dosages and limits of human exposure.

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16

Energy Consumption and Reduction Strategies in Food Processing

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16.1 Introduction

The whole manufacturing industry utilizes almost one-third of the total energy consumed in the United States. Over the past 15 years, the energy intensity of the US economy has been decreased by approximately 50% mainly because of the applications of efficient manufacturing technologies (Fischer et al., 2007). The energy cost in the food industry ranks third among all input costs behind raw materials and labour (US EPA, 2007). Energy conservation technologies can reduce the total energy consumption of a food process and thus reduce the total production costs. Energy efficiency improvement in the food industry should not be considered to only provide economic benefit since it may also provide benefits for environmental protection, social sustainability, energy supply security and industrial competitiveness. An important issue in the analysis of energy consumption in food processing facilities is the selection of an indicator, which can be used to evaluate the energy intensity and monitor the improvement of energy efficiency in the facilities. The most common indicator is the energy use per unit of output (Ramirez et al., 2006a; b & c). Since there is a large variation in products and processes in different food processing facilities, economic values such as total value of shipment and value

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added via processing are commonly used as a measure of output from a food processing facility (U.S. Census Bureau, 2010).

Two main types of energy: fuels such as coal, natural coal and petroleum oil, and electricity are used in food processing facilities. Steam and electricity are two direct energy carriers used in food processing facilities. Since electricity generation efficiency is only 30–40%, the energy stored in the fuels consumed to generate electricity is 3 times that of the energy in the electricity generated. Steam is generated by the combustion of fuels at a conversion efficiency of 80%. Different energy sources may be used in different food processes and unit operations. In energy analyses, factors such as 3.4 and 1.25 are usually used to multiply the electricity and steam consumption for comparison, respectively (Tragardh, 1986).

The goal of an energy analysis is to find ways of reducing energy consumption or conservation of energy. Simple approaches to reduce the use of fossil energy include (Poulsen, 1986):

- Development of new food products without the requirement of energy intensive preservation.
- Reduction of heat loads during processing.
- Improvement of the performance of equipment.
- Utilization of waste heat or renewable energy such solar energy in processing.

However, energy conservation measures will be adopted in the food industry only if they are cost-effective. In food processing facilities, various energy intensive unit operations such as sterilization/pasteurization, chilling/freezing and evaporation/dehydration are used to manufacture different food products. Special attention should be paid to these energy intensive operations (Wang, 2008).

In this chapter, the energy consumption in the food industry is briefly reviewed with aspects to energy indicators, energy sources and energy uses in different processing sectors and production of different products. The energy conservation technologies applied to several energy intensive unit operations including thermal processing, refrigeration and dehydration are discussed.

16.2 Energy consumption in the food industry

16.2.1 Energy consumption in the food manufacturing industry

Food processes utilize significant amounts of labour, machinery and energy to convert edible raw materials into higher-value food products. In the United States, the food processing industry is one of the largest manufacturers. The

shipment value from the food industry was increased from \$538 in 2006 to \$646 billion in 2010. The shipment value from the food industry was about 10.72% and 13.15% of the total shipment value from all manufacturing industries in the United States in 2006 and 2010, respectively. The food industry is also a large energy consumer. The total cost for purchasing fuels and electricity in the food industry was \$9.92 billion in 2006, which was 9.57% of the total energy costs for all manufacturing industries (US Census Bureau, 2010). In the European Union, the food and tobacco sector, on average, accounted for about 8% of the total energy demand in the whole manufacturing sector in 2001. In the Netherlands, the food and tobacco sector accounted for about 9% of the total industrial energy demand and 23% of the industrial value added (Ramirez et al., 2006a).

There is a large variation in the shares of commercial energy used for processing foods in developing countries due to different levels of urbanization, income and processing technology. More urbanization and income lead to more consumption of processed foods and thus increase the energy consumption in the food industry. On the other hand, more industrialization usually adopts more energy efficient technologies in the food industry and thus reduces the energy consumption. The energy consumption for the same operations may differ as a consequence of the type of equipment used, operating practice, ambient temperature, local infra-structure and the skills of staff. In the developing countries, the post-harvest food system requires 2 to 4 times more energy than farming, the share of commercial energy which is used for food processing, such as milling, crushing and food transport and cooking, ranges between 22% in Africa and 80% in the Near East (Parikh and Syed, 1988). In Thailand, the food and beverage manufacturing sector accounted for about 30% of the total energy consumption and generated 16% of the total added value in all manufacturing sectors in 2000 (Bhattacharyya and Ussanarassamee, 2004).

The current energy cost is about 2% of the total production costs in the food industry in the developed countries (Ramirez et al., 2006a). In the United States, the energy indicator based on economic values was increased from 0.78 cents/dollar shipment value in 2002 to 1.84 cents/dollar shipment value in 2006. The energy indicator for the food industry increased 2.36 times from 2002 to 2006 while the energy indicator for all manufacturing sectors increased 2.1 times during the same period (US Census Bureau, 2010). It consumed 2.74 MJ of energy for each dollar shipment value in the food industry of the United States in 2002 (US EPA, 2007). In the four European countries including France, Germany, the Netherlands and the United Kingdom, the energy indicator, which was based on energy consumption in MJ per ton of finished products in the meat industry, was increased between 14% and 48% in the 1990s (Ramirez et al., 2006b). Generally, the increase of the energy indicator in the food industry could be partially caused by the increase in the prices of major energy sources and tougher government regulations. The

changes in food products and processes such as frozen and cut meat products might also contribute to the increase of the energy indicator.

16.2.2 Energy sources in the food manufacturing industry

The main energy sources used in the food manufacturing industry include petroleum, natural gas, coal, renewable energy and electricity. Figure 16.1 shows the delivered energy consumption in terms of the types of fuels in the food processing industry of the United States in 2002 (US EPA, 2007). Natural gas and electricity are two main energy sources used in the food industry of the United States, which were 52% and 21% of the total energy consumed respectively in 2002. In the United States, although the purchased electricity is only 21% of the total consumed energy, the food industry spent nearly 47% of its energy expense on average to purchase electricity because the electricity price per unit of energy content is higher than that of other energy sources (Wang, 2008). While natural gas remains the largest energy source, consumption of renewable energy sources is projected to grow most rapidly as the food industry becomes more proficient in recovering and utilizing process and agricultural wastes. It should be noted that the food manufacturing industry produces about 9% of the electricity with its onsite power systems, 95% of which are the heat and power cogeneration systems in the United States in 2006 (US EPA, 2007). Biomass such as wood is a main non-commercial energy

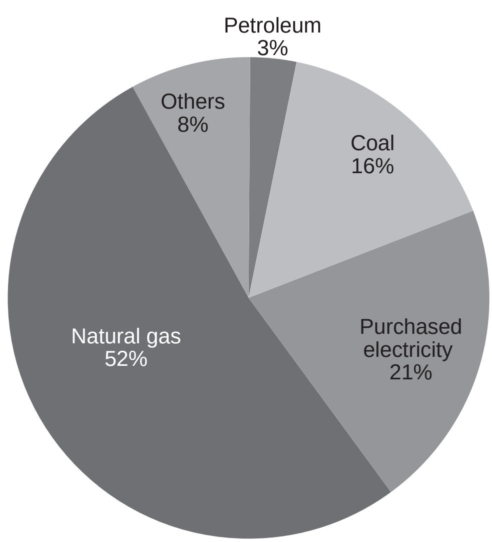

Figure 16.1 Delivered energy consumption by the type of fuels in the food manufacturing industry in the United State in 2002 (US EPA, 2007).

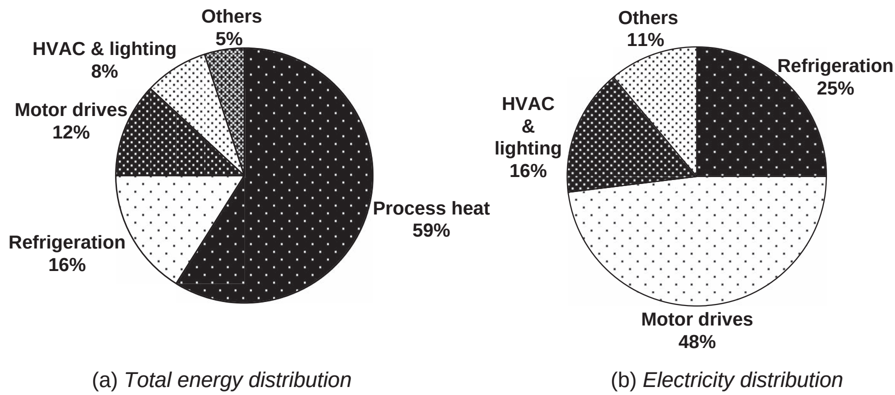

Figure 16.2 Energy consumption by the end users (Adapted from Wang, 2008).

source used in the developing regions. In the developing regions, a large amount of non-commercial energy sources are used for cooking. In Africa, the relative shares of energy used for processing, transport and cooking in the whole food system are 25:14:61 if only commercial energy is considered, and 10:3:81 if both commercial and non-commercial energy is considered. In Latin America, the relative shares are 21:14:65 if only commercial energy is considered, and 31:8:61 for the total energy. In the Near East, the relative shares are 12:7:81 and 12:6:82 for commercial energy and total energy, respectively. In the Far East, the shares are 23:11:66 and 18:4:78, respectively (Parikh and Syed, 1988).

The end users of energy in the food industry are process heating, process cooling and refrigeration, machine drive and miscellaneous users. About half of all energy inputs are used to process raw materials into products. Fuels are mainly used for process heat and space heating while electricity is used for refrigeration, motor drives and automation. Figure 16.2 gives the energy consumption by the end users. Process heat for thermal processing and dehydration consumes approximately 59% of total energy in the whole food industry. Steam is one of important processing media in food processing facilities. Boiler fuel is nearly one-third of the total energy consumption. Ovens and furnaces are also widely used in thermal processes. Refrigeration uses approximately 16% of total energy in the whole food industry. Motor drives represent 12% of the total energy use. The non-process uses including space heating, venting, air conditioning, lighting and onsite transport only consumes about 8% of the total energy (Okos et al., 1998; Wang 2008). In the whole food industry, about 25% of the electricity is used for process cooling and refrigeration, and 48% for machine drive (Okos et al., 1998; Wang, 2008). However, in the meat sector, refrigeration consumes between 40% and 90% of total electricity use during production time and almost 100% during

non-production periods (Ramiez et al., 2006a). The non-process uses for space heating, venting, air conditioning, lighting and onsite transport consumes about 16% of electricity (Okos et al., 1998; Wang, 2008).

16.2.3 Energy use in different food manufacturing sectors

In the United States, the meat manufacturing sector is the largest individual sector in the food industry in terms of shipment value followed by grain and oilseed milling, fruit and vegetable, and bakeries and tortilla. Among the nine different food manufacturing sectors, the grain and oilseed milling, and the meat manufacturing are two large energy consumers in the food industry as shown in Table 16.1, which consume 22.3% and 20.7% of the total energy for 10.7% and 27.8% of total shipment values in the whole food industry, respectively (Wang, 2008). However, in other developed countries, the energy demand distribution in different food sectors may be different. In the Netherlands in 2001, each of 1) the processing and preserving of fruits vegetable, 2)

Table 16.1 Energy use and indicator in different food manufacturing sectors in the United States in 2006 (Adapted from Wang, 2008)

Manufacturing sector	Shipment value (Million US$)	Total energy cost (Million US$)	Energy indicator (cents energy cost/$ shipment value)	Percent of electricity cost among the total energy cost (%)	Percent of total energy cost in the whole industry (%)
3111 Animal food manufacturing	33,988	522	1.54	47.1	5.3
3112 Grain and oilseed milling	57,667	2,198	3.81	37.0	22.3
3113 Sugar and confectionery product manufacturing	28,225	577	2.04	36.6	5.8
3114 Fruit and vegetable preserving and specialty food manufacturing	56,279	1,302	2.31	44.3	13.1
3115 Dairy product manufacturing	75,428	1,184	1.57	52.4	11.9
3116 Animal slaughtering and processing	149,577	2,055	1.37	53.4	20.7
3117 Seafood product preparation and packaging	10,849	246	2.27	45.5	2.5
3118 Bakeries and tortilla manufacturing	54,173	911	1.68	54.7	9.2
3119 Other food manufacturing	71,602	926	1.29	52.9	9.3

production, processing and preserving of meat products, 3) manufacturing of vegetable oil and animal fat, 4) manufacturing of dairy products, 5) manufacturing of prepared animal feeds, and 6) manufacturing of grain mill, starches and starch products consumed about 10–15% of the total energy input into the whole food industry (Ramirez et al., 2006a).

In most of the developing countries, cereal products have the largest share among all food products since grains are the staple foods in developing regions. The shares of cereal products are 65% for Africa, 35% for Latin America, 69% for the Near East and 77% for the Far East. Some developing countries may have a special feature of food product structures. The share of sugar is 90% in Mauritius and 78% in Cuba. Columbia, Mexico and Argentina have high shares in livestocks. Some African countries, Brazil and Sri Lanka, have high shares in cassava, coffee, and tea, respectively. Generally, the shares of livestock and milk products depend on the degree of urbanization and income levels (Parikh and Syed, 1988).

Different food manufacturing sectors have different energy indicators. In the United States, the grain and oilseed milling has the highest energy indicator while the meat manufacturing sector has the lowest energy indicator as shown in Table 16.1. In the United States, it required 3.81 cents and 1.37 cents to generate 1 dollar of shipment values in the grain and oilseed milling sector and the meat manufacturing sector, respectively, compared to the average of 1.84 cents per dollar shipment value in the whole food industry in 2006. Within the food industry, the dairy product manufacturing, the meat manufacturing and bakeries and tortilla manufacturing sectors particularly have a high electricity demand. More than half of the energy expenses in these three sectors were used to purchase electricity. The grain and oilseed milling, and sugar and confectionery sectors require a high fuel demand. About 63% of the energy expenses in these two sectors were used to purchase fuels (Fritzson and Berntsson, 2006).

16.2.4 Energy use for production of different food products

The amount of energy used for producing a given amount of products highly depends on the type of the products. Table 16.2 gives the energy use for manufacturing different food products in the Netherlands in 2001 (Ramirez et al., 2006a). The ranking of food commodities in energy consumption does not follow the same pattern as the volumes processed. Production of milk powder and whey powder consumed 9385 MJ and 9870 MJ heat per ton of products, respectively while production of pasta consumes only 2 MJ of heat per ton product. Production of wheat starch consumes 2960 MJ of electricity per ton of product while production of beet pulp only consumes 5 MJ electricity per ton of the product.

Table 16.2 Energy use for production of different food products in the Netherlands in 2001 (adapted from Ramirez et al., 2006a; Wang, 2008)

Product	Specific electricity consumption	Specific fuels and heat consumption	Unit
Meat sector:			
Beef and sheep	341	537	MJ/ton dress carcass weight
Pig	465	932	MJ/ton dress carcass weight
Poultry	1008	576	MJ/ton dress carcass weight
Processed meat	750	3950	MJ/ton product
Rendering	234	1042	MJ/ton raw material
Fish sector:			
Fresh fillets	129	6	MJ/ton product
Frozen fish	608	6	MJ/ton product
Prepared and preserved fish	482	1062	MJ/ton product
Smoked and dried fish	12	2077	MJ/ton product
Fish meal	684	6200	MJ/ton product
Fruits and vegetables:			
Potatoes product	5722		MJ/ton product
Un-concentrated juice	250	900	MJ/ton product
Tomato juice	125	4789	MJ/ton product
Frozen vegetables and fruits	738	1800	MJ/ton product
Preserved mushrooms	2898		MJ/ton product
Vegetables preserved by vinegar	2178		MJ/ton product
Tomato ketchup	380	1700	MJ/ton product
Jams and marmalade	490	1500	MJ/ton product
Dried vegetables and fruits	1500	4500	MJ/ton product
Crude and refined oil	672		MJ/ton product
Dairy products:			
Milk and fermented products	241	524	MJ/ton product
Butter	457	1285	MJ/ton product
Milk powder	1051	9385	MJ/ton product
Condensed milk	295	1936	MJ/ton product
Cheese	1206	2113	MJ/ton product
Casein and lactose	918	4120	MJ/ton product
Whey powder	1138	9870	MJ/ton product
Starch and starch products:			
Wheat starch	2960	8800	MJ/ton product
Maize starch	1000	2331	MJ/ton product
Potato starch	1425	3564	MJ/ton product
Prepared animal feeds:			
For farm animals	475		MJ/ton product
For pets	2306		MJ/ton product
Sugar:			
Refined sugar	555	5320	MJ/ton product
Beet pulp	5	1820	MJ/ton product

Table 16.2 (*Continued*)

Product	Specific electricity consumption	Specific fuels and heat consumption	Unit
Other products:			
Sweet biscuits	4581		MJ/ton product
Waffles and wafers	3195		MJ/ton product
Soup and broths	7659		MJ/ton product
Pasta	648	2	MJ/ton product
Flour	420	30	MJ/ton product
Cacao beans	6384		MJ/ton product
Non roasted coffee	141	1597	MJ/ton product
Roasted coffee	518	1997	MJ/ton product
Extracts of coffee solid form	15675		MJ/ton product
Beer	19.5	153	MJ/hl product
Mineral water and soft drinks	133	199	MJ/1000 l product
Unsweetened water and soft drinks	120	360	MJ/1000 l product

16.3 Energy efficiency in the food industry

Energy and exergy efficiencies in food processing facilities vary with end-users and production lines. Ozdogan and Arikol (1995) investigated the energy and exergy efficiencies of different energy users including processing heat, space heating, water heating, illumination and motor power in the Turkish food industry. In the Turkish food industry, the energy efficiency for heat was from 60% to 75%. Since heat at a temperature below 200 °C accounted for 97.5% of the total thermal energy demand, the exergy efficiency for the supply of heat in the Turkish food industry was only from 10% to 18%. Motor power had the highest energy and exergy efficiencies at 90% while the energy and exergy efficiencies for illumination were only 18.5% and 17%, respectively. On average, the energy and exergy efficiencies in the Turkish food industry were 75.1% and 23.5%, respectively.

Fischer et al. (2007) reported that around 57% of the primary energy inputs into the whole industry are lost before reaching intended process activities in general. Estimates from several studies indicate that on average, savings of 20 to 30% energy can be achieved without capital investment, using only procedural and behavioural changes. Industrial energy consumption can be further cost-effectively reduced by 10 to 20% through well-structured energy management programmes that combine energy conservation technologies, operation practices and management practices. Table 16.3 is an example to show the potential energy savings in the British industry which used 2410 PJ of energy in 1986 (Wang, 2008). As seen from Table 16.3, the potential for the industrial energy savings was between 25% and 34% of the total industrial fuel

Table 16.3 Potential energy savings in British industry (Adapted from Wang, 2008)

Type of energy saving	Amount (PJ)	Percent of total energy consumption (%)
Waste heat recovery	216–288	8.96–11.95
Waste as fuel	108–180	4.48–7.47
Improved instrumentation and control	72–108	2.99–4.48
Heat pumps	36	1.49
Process insulation	36	1.49
Improved drying and evaporation practice	36	1.49
Industrial combined heat and power plants	36	1.49
Improved methods of driving machinery	72–108	2.99–4.48
Total savings	612–828	25.39–34.36

used. The waste heat recovery was the biggest contribution to the total energy savings, which could save 8.96–11.95% of the total industrial fuel use. The use of processing waste as fuels could save another 4.48–7.47% of the total fuel consumption. Prospective measures for improving energy efficiency in the food industry should be technically feasible and economically practical. Table 16.4 is an example to show the potential energy savings identified for a Nestle factory in Switzerland (Muller et al., 2007). In the Nestle facility, insulation of high-temperature condensate return pipes and using a low-pressure air blower to replace the use of high-pressure compressed air for the sealing operation of process units could save 1127 GJ/year (or 338 MWh/year) fuels and 166 MWh/year electricity, respectively.

Table 16.4 Summary of some energy savings identified in a Nestle factory (adapted from Muller et al., 2007 and Wang, 2008)

Measure	Energy type	Energy saving (MWh/year)	Estimated payback (year)
Replacing compressed air usage by dedicated blower	Electricity	166	2
Regulation of HVAC	electricity	80	negligible
Removing stand-by of air compressors with a VSD unit	electricity	69	23
Fixed compressed air leakage	electricity	50	negligible
Insulating pipes of high temperature condensate return	Fuels	338	1.5
Vacuum production in dryer	Fuels	150	1
Regulation of steam user	Fuels	50	negligible

16.4 Energy conservation in the food industry

16.4.1 Energy conservation in steam generation system

Most of the food processing facilities have large steam and/or hot water demands. Boilers are the largest fuel user to provide steam as process heat for different unit operations such as sterilization, pasteurization, evaporation and dehydration in the food industry. Boilers consume about one third of the total energy use or more than half (50%) of the fuel use. Appreciable energy is lost from stack flue gas, blowdown water, steam leaks and poor surface insulation during steam generation and distribution (Wang, 2008). The energy savings for a boiler system can be achieved through the optimization of design and operation, and waste-heat recovery. The optimization may include:

- Proper size of a boiler.
- Proper pressure and temperature of steam.
- Optimal amount of excess air.
- Optimal amount of blowdowns.

Over 20% of the total heat is normally exhausted from a boiler through a stack without a waste-heat recovery unit. A stack heat recovery system can improve the boiler efficiency by as much as 15%. An economizer can efficiently recover wasted stack heat and transfer it to boiler makeup water. An increase in water temperature by every 6 °C or decrease in flue gas temperature by every 25 °C can save approximately 1% of the boiler fuel. The hot flue gas can also be used to preheat the air into a boiler. An increase in air temperature by every 4.5 °C can increase the boiler efficiency by 1%. If the right equipment is used, up to 78% of the heat stored in blowdown water can be recovered via either a heat exchanger or a flash steam generator (Wang, 2008). A steam distribution system is used to carry the steam from a boiler to end-use equipment in a food processing plant. If steam lines have leaks, large amounts of steam loss can be a major waste of energy from a steam distribution system. Improving the insulation of steam distribution systems may save an average of 3–13% of energy (Einstein et al., 2001).

16.4.2 Energy conservation in compressed air system

Compressed air is another important processing medium for conveying foods and process control in food processing facilities. The production of compressed air can be one of the most expensive processes in manufacturing facilities. Proper improvements to compressors and compressed air systems

can save 20–50% of the energy consumed by the systems. These energy conservation technologies for a compressed air system include the use of high-efficiency and variable speed motors, reduction of inlet air temperature, use of a cooling or waste heat recovery unit for compressors, reduction of air leaks along an air distribution line, reduction of air pressure and use of localized air delivery system (Mull, 2001).

16.4.3 Energy conservation in power system

Motor drives and refrigerators are two large electricity users in the food industry, which consumes about 48% and 25% of the total electricity use, respectively (Wang, 2008). The energy loss in a motor is in the range of 5 to 30%. The energy losses in motors are usually caused by low power factor, improper motor load and poor control. Most motors operate in a fashion that requires both real power due to the presence of resistance and reactive power due to the presence of inductance in the motors. Increase of power factors should be considered for improving electrical efficiency and reducing the energy costs of motors. Motors are designed to operate most efficiently under their rated loads. Therefore, it is an effective way to conserve energy by matching the required loads with the rated loads of motors. A variable speed motor may result in significant energy savings when purchasing a new motor (Wang, 2008).

16.4.4 Energy conservation in heat exchangers

Heating and cooling of foods is achieved in heat exchangers. Heat exchangers also play a key role in waste heat recovery. The area or the size of heat exchangers affects their effectiveness and capital and operating costs. Several energy conservation technologies including heat transfer enhancement, fouling removal, optimization of heat exchanger design and optimization of a heat exchanger network have been used to improve the energy efficiency of heat exchangers (Wang, 2008). Heat transfer enhancement techniques can be used to improve the performance of an existing heat exchanger, reduce the size and cost of a new heat exchanger, and increase the energy efficiency of a heat exchanger and thus reducing operating cost (Wang et al., 2000a & b). Fouling and cleaning of heat exchangers are serious industrial problems. It was reported that fouling caused an increase of up to 8% in the energy consumption in liquid milk plants and about 21% of the total energy was used to clean milk pasteurization plants (Ramirez et al., 2006c). Novel methods such as nano-coatings have been developed to reduce the fouling in heat exchangers (Kananeh et al., 2010). Process integration technology for improving energy efficiency has been widely used around the world. Systematic methods for the

design of heat exchanger networks have been developed to retrofit a heat exchanger network (Smith, 2000).

16.4.5 Energy conservation through waste heat recovery

Any processing air, vapour and water effluent streams above the ambient temperature may be an energy source. Boiler flue gas, boiler blowdown water, steam condensate, exhaust gas from dryers and ovens, cooling air and water from air compressor and large motors, and vapour from cookers are the examples of waste heat sources. By recirculation and recovery of waste heat, the energy consumption of food processing facilities could be cut by 40%. Waste heat in food processing facilities is usually a low-or medium-temperature energy source. A heat pump is a device that absorbs and transfers energy from an energy source at a low temperature to an energy sink at a higher temperature at an additional expense of external work (Wang, 2008). A heat pump may be used to raise the temperature of a waste source so that the waste heat can be transferred to a fluid stream at a higher temperature (Wang, 2008).

16.4.6 Food waste to energy

Large quantities of waste in both liquid and solid forms are produced by the food processing industry. Traditionally, part of those wastes is processed as animal feeds. Large amounts of solid food processing wastes are buried in landfills at a cost while liquid food processing wastes are released untreated into rivers, lakes and oceans, and disposed of in public sewer systems. Conversion of food processing wastes into useful energy products such as bioethanol, biodiesel, bio-oil, biogas, syngas, steam and electricity in a food processing facility could result in significant savings for the food manufacturing industry in terms of reducing the amount of energy purchased and waste disposal costs. The energy utilizations of food processing wastes are dependent upon a basic understanding of 1) operating conditions of a food processing facility, 2) waste types, availability and energy potential, and 3) process and equipment for handling and conversion of the waste (Wang, 2008). Comprehensive technical and cost analyses are essential to determine the feasibility and economics of an energy conversion process for utilizing food process wastes. Wet food processing wastes are usually better suited for biological processes such as anaerobic digestion and fermentation while dry wastes are better for thermochemical conversion processes such as combustion, gasification and pyrolysis. Fermentation, transesterification, pyrolysis and liquefaction produce liquid fuels for use as transportation fuels. Combustion, gasification and anaerobic digestion produce gaseous energy products, which are suitable for use at the production location (Wang, 2008).

16.5 Energy conservation in energy-intensive unit operations

Thermal processes such as pasteurization and sterilization, chilling and freezing, and evaporation and drying are energy intensive unit operations in the food industry for food preservation and safety. It is a need for food manufacturers to combine food safety and quality with energy conservation. The energy saving opportunities for each unit operation includes three aspects:

- improvement of energy efficiency for existing units;
- replacement of energy-intensive units with novel units; and
- use of renewable energy sources, particularly food processing wastes.

Improvement of the energy efficiency of the existing units is still the main consideration for the decrease of energy costs. Meanwhile, novel energy conservation technologies such as heat pump, supercritical-fluid processing, non-thermal sterilization and pasteurization processes, and thermal energy-powered refrigeration cycles have been introduced into food processing facilities. Capital investments should be incorporated with cutting-edge technologies and processes in anticipation of the future when energy is likely to be an increasing cost of doing business. The energy saving opportunities and technologies for pasteurization and sterilization, evaporation and drying, and chilling/freezing operations are discussed in the following sections.

16.5.1 Energy savings in pasteurization and sterilization

16.5.1.1 Maintenance and optimization of existing systems Thermal pasteurization of liquid foods such as milk and fruit juices is a well-established and effective means of terminal decontamination and disinfection of these products. Thermal processing is also an important method of food preservation in manufacturing canned foods and retortable pouches. The basic function of a thermal process is to inactivate pathogenic and food spoilage causing microorganisms in foods. Simpson et al. (2006) developed a mathematical model to estimate total and transient energy consumption during heating of retortable shelf-stable foods. According to the results from Simpson et al. (2006); retort insulation can reduce 15–25% of current energy consumption depending on selected conditions. Furthermore, in batch retort operations, maximum energy demand occurs at the venting step that only lasts for the first few minutes of the process cycle while very little energy is needed thereafter to maintain the process temperature. The increase in the initial temperature of food products can reduce the peak energy demand in the order of 25–35%. Also it is customary to operate the retorts in a staggered schedule so that no more than one retort is vented at any one time. Thus operating practice can also reduce the peak energy demand during retorting.

16.5.1.2 Application of emerging energy-efficient technologies Pasteurization and sterilization require a heating step and a cooling step. A heat pump can be used to couple the energy flow between the heating unit and cooling unit during pasteurization. A heat pump functions in a manner similar to a refrigerator. It consists of a condenser for high-temperature heat exchange, a compressor, an evaporator for low-temperature heat exchange, and an expansion value to decrease the pressure of working liquid (Wang, 2008). Figure 16.3 shows a liquid to liquid heat pump for the pasteurization of milk (Ozyurt et al., 2004; Wang, 2008). The hot pasteurized milk is cooled by the evaporator of the heat pump while the cold raw milk is heated by the condenser of the heat pump. For the pasteurization temperature at 72 °C and coagulation temperature at 32 °C, the measured C.O.P of the heat pump ranged from 2.3 to 3.1. The heat pump system can save 66% of the primary energy compared to traditional plate and double jacket milk pasteurization systems (Ozyurt et al., 2004).

Thermal processes are usually considered to be energy intensive. Also the slow heat transfer through food products is usually a limiting factor for thermal treatment of food products. Non-thermal pasteurization techniques including food irradiation, pulsed electric field treatment and high pressure processing, as well as microwave sterilization have been developed to replace the conventional thermal sterilization and pasteurization processes for saving

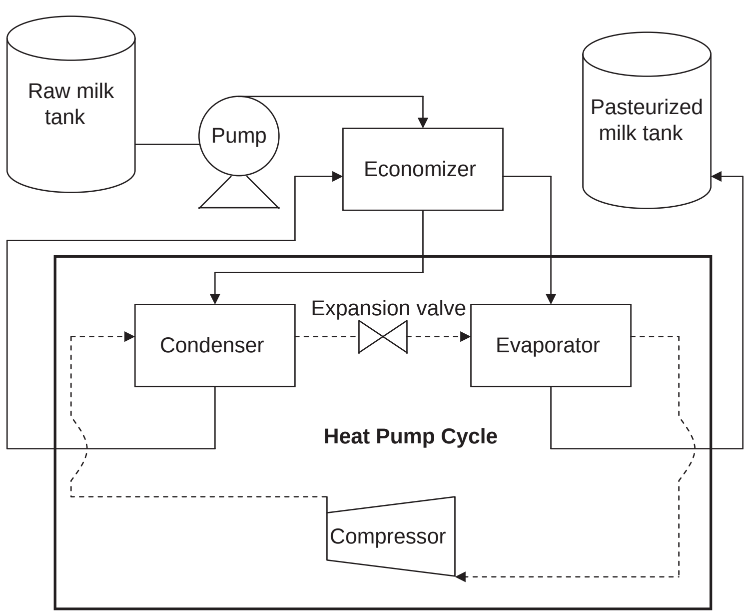

Figure 16.3 Schematic diagram of a liquid-liquid heat pump system for pasteurization of milk (Adapted from Wang, 2008).

energy, and improving product quality and safety (Wang, 2008). These non-thermal processing times are usually very short. For example, during high-pressure processing, foods are exposed to a pressure up to 1000 MPa for a few minutes. Pulsed electric field treatment is based on the delivery of pulses at high electric field intensity of 5–55 kV/cm for a few milliseconds. Food irradiation lasts for several seconds to several minutes. Most alternative preservation processes can achieve the equivalent effect of thermal pasteurization but not sterilization (Lado and Yousef, 2002).

Food irradiation is a cold process, which can damage the DNA of living cells effectively so that the living cells become inactivated. Compared with thermal pasteurization, food irradiation is a more efficient pasteurization method for solid foods without causing significant changes in taste and quality of the products. The energy used for food irradiation is very small. The dose of food irradiation is usually less than 10 kGy which is energy equivalent to 10 kJ/kg foods. The increase of food temperature due to irradiation is less than 3 °C (Loaharanu, 1996).

Microwave heating has been used for high temperature-short time (HTST) sterilization/pasteurization of foods, particularly thick food items. Because of the low thermal conductivity, it is impossible to achieve HTST treatment for food items with a several-centimetre thickness by conventional heating methods. Microwave energy can penetrate into the food items and cause a rapid temperature rise to pasteurization temperatures. Huang and Sites (2007) used a microwave heating system for in-package pasteurization of ready-to-eat meats. They observed that the overall inactivation rate of *Listeria monocytogens* for the traditional water immersion pasteurization at the same surface temperatures was only 30–75% higher than that of microwave in-package pasteurization. However, microwave pasteurization is much faster than the water immersion pasteurization. During microwave heating, electrical energy is first converted into microwave energy. The microwave then interacts with foods and is converted into heat. Therefore, there are two efficiencies: microwave generation efficiency and microwave absorption efficiency. The absorption of microwave energy by water was found to be 86–89% while the conversion efficiency of electrical energy to microwave energy was only about 50%. Therefore, the overall electricity to the heat absorbed by water was only around 44% (Lakshmi et al., 2007; Wang, 2008). It requires about 0.36 MJ of heat or 0.22 kWh of electricity for a microwave unit at 45% energy efficiency to pasteurize 1 kg of food products (Wang, 2008).

High-quality fruit juices with sufficient product safety cannot be achieved with conventional thermal sterilization or pasteurization. Also, the need to reduce energy costs stimulates the search for non-thermal techniques such as pulsed electric fields treatment and high-pressure processing (Toepfl et al., 2006). Application of an external electrical field to a biological cell induces an electrical potential across the cell membrane. If the electrical potential exceeds a critical level, local structural changes of the cell membranes will

occur. As a consequence, a drastic increase in membrane permeability occurs, which impairs on the irreversible loss of physiological control systems and therefore causes cell death. Pulsed electric fields treatment has been used to pasteurize liquid foods (Heinz et al., 2003). Application of pulsed electric fields treatment at low temperatures has a potential to provide food products with a fresh-like character and high nutritional value. The application of pulsed electric fields for treatment of liquid foods at 30 °C requires a specific energy input of 100 kJ/kg or more (Heinz et al., 2003). Pulsed electric fields treatment is usually considered to have a higher energy input than a thermal process with heat recovery capacity. When operating at elevated treatment temperature and making use of synergetic heat effects, the pulsed electric field energy input might be reduced close to the amount of 20 kJ/kg required for a conventional thermal pasteurization process with 95% of heat recovery (Toepfl et al., 2006). Due to high production costs, commercial applications of pulsed electric fields treatment as an alternative to traditional thermal process have not yet been accomplished (Heinz et al., 2003).

A high-pressure process inactivates micro-organisms by targeting on the membranes of biological cells. During pressurization, water and acid molecules show increased ionization. This ionization change in living cells causes the major killing effect on living cells during pressurization. Although atomic bonds are barely affected by a high pressure, alternation of proteins or lipids can be observed when exposed to a high pressure. Lethal damage occurs when alternation of proteins or lipids occurs in the membranes of biological cells (Manas and Pagan, 2005; Toepfl et al., 2006). Theoretically, the compression work and energy required for the resulted temperature increase due to pressurization is about 52 kJ/kg and 70 kJ/kg upon compression of pure water up to 600 MPa, respectively (Toepfl et al., 2006).

16.5.2 Energy savings in concentration, dehydration and drying

16.5.2.1 Maintenance and optimization of existing systems Concentration, dehydration and drying are a common unit operation in food processing facility to lower the moisture content of foods in order to reduce water activity and prevent spoilage or reduce the weight and volume of food products for transport and storage. Dehydration and drying are an energy-intensive unit operation because of the high latent heat of water evaporation and relatively low energy efficiency of industrial dryers. Industrial dryers consume about 12% of the total energy used in all manufacturing sectors (Bahu, 1991). The typical temperature during air drying is between 65 °C and 85 °C. Loss of moisture from food products and high temperature processing during air drying may cause undesirable effects on the textural properties and nutritional

values of the products. Other common drying methods include microwave drying, freezing drying and vacuum drying.

A drying process is a simultaneous heat and mass transfer operation. The energy required for evaporation of water, which is dependent on temperature and pressure, is in the range of 2.5–2.7 MJ/kg. However, total energy input into a conventional dryer is in the range of 4–6 MJ/kg of removed water depending on the thermal efficiency of the drying system. Several studies have been conducted on exergy analyses of food drying (Midilli and Kucuk, 2003; Dincer and Sahin, 2004; Akpinar, 2004; Akpinar et al., 2005 and 2006; Ozgener and Ozgener, 2006; Colak and Hepbasli, 2007; Corzo et al., 2008). The energy and exergy efficiencies of a pasta drying process were found to be 75.5–77.09%, and 72.98–82.15%, respectively (Ozgeber and Ozgener, 2006). In order to increase the energy efficiency, the air leaving the dryer can be re-circled back to the dryer. The exergy efficiency decreases with the increase in air temperature and velocity. Corzo et al. (2008) conducted exergy analyses of thin layer drying of coroba slices. At drying temperatures from 71 to 93 °C and drying air velocities from 0.82 to 1.18 m/s, the exergy efficiency of the thin layer drying of coroba slices was in the range from 97% and 80%. The exergetic efficiency for drying red pepper slices in a convective type dryer varied from 97.92% to 67.28% at the inlet temperature from 55 to 70 °C and a drying air velocity of 1.5 m/s (Akpinar, 2004).

16.5.2.2 Application of emerging energy-efficient technologies Several methods have been used to improve the energy and exergy efficiencies of the evaporation, dehydrating and drying process. Mechanical processes such as filtration and centrifugation can be used to remove as much water as possible before evaporation and drying. Evaporation is an energy intensive unit operation. Mechanical recompression evaporation is the most commonly used for concentrating dilute solutions in food processing. Membrane technology has a potential to reduce overall energy consumption in combination with the evaporation technology (Kumar et al., 1999). A multiple-effect evaporator system is a simple series arrangement of several evaporators, which use steam to remove product moisture by evaporation. The evaporated water vapour from food products are collected and used as the steam for the next evaporator in the series. This collection and reuse of vapour results in smaller energy requirements to remove product moisture. The greater the number of effects in the series, the smaller is the energy consumption. It was found that changing from four effect evaporators to five evaporators could save 20% energy. However, the number and arrangement of evaporators in series should also be determined by the economics of the process (kaya and Sarac, 2007; Simpson, et al., 2008).

Heat pumps have been used to increase the drying efficiency of a convectional air dryer (Perera and Rahman, 1997). A fan is usually used to provide air movement in the drying chamber. In a heat pump dehumidifier, the evaporator is used to remove the moisture in the moist air exiting the drying chamber, and the condenser is used to increase the temperature of the dry air

from the evaporator. The hot dry air is then sent back to the drying chamber (Perera and Rahman, 1997; Adapa and Schoenau, 2005; Kiatsiriroat and Tachajapong, 2002). A heat pump can also be used to extract heat from a low-temperature energy source such as geothermal energy through its evaporator and upgrade the extracted heat to a high-temperature heat source at its condenser for drying (Kuzgunkaya and Hepbasli, 2007).

Supercritical fluids such as supercritical carbon dioxide can be used to remove moisture from foods (Brown et al., 2008). Supercritical CO_2 has a low critical temperature and pressure (31.1 °C and 7.3 MPa). Therefore, drying with supercritical CO_2 can be operated at a much lower temperature than conventional air drying. However, since supercritical CO_2 is a non-polar solvent, the water solubility in supercritical CO_2 is 4 mg/g at 50 °C and 20 MPa and 2.5 mg/g at 40 °C and 20 MPa (King et al., 1992; Sabirzyanov et al., 2002). Therefore, small quantities of polar co-solvents such as ethanol are usually added into the supercritical CO_2 to increase the solubility of polar water in supercritical CO_2. Supercritical CO_2 drying has been found to generate more favourable re-hydrated textural properties than the air dried equivalents (Brown et al., 2008).

16.5.3 Chilling and freezing

16.5.3.1 Maintenance and optimization of existing systems Food processing facilities make heavy use of refrigeration. It is estimated that the refrigeration system uses as much as 15% of the total energy consumed worldwide. In the whole US food industry, about 25% of the electricity is used for process cooling and refrigeration (Okos et al., 1998). The dairy sector and the meat sector are likely to be the highest and second highest users of refrigeration respectively. Generally, energy conservation for refrigeration unit operations can be achieved by:

- improved insulation;
- best practice; and
- use of novel refrigeration cycles powered by waste heat.

Air blast chillers or freezers are widely used in the food industry. The fans of air blast chillers or freezers add heat load to chillers or freezers during operation. Since the heat generated by fans increases with required air load, it is critical to optimize the air velocity to minimize the heat generation and maximize the refrigeration effect during air blast chilling or freezing of food products. The generally accepted air velocity is 4 m/s for tunnel blast freezers. The use of variable speed fans could achieve up to 44% of energy savings. The applications of air baffles, air turning vanes, fan inlet cone and outlet diffuser are also cheap and simple energy savings measures. Computational fluid dynamics (CFD) models have been widely used to improve the air distribution in air blast chillers or freezers (Dempsey and Bansal, 2012).

During air blast chilling/freezing, the heat transfer from the cold media of air to the inside of foods must pass two layers of thermal resistance: the external resistance to heat convection between the cold air and the food surface, the internal resistance to heat conduction in the solid foods. The Bio number is the ratio of the internal resistance to the external resistance, which is expressed as (Singh and Heldman, 2001):

$$Bio = \frac{hl}{k} \tag{16.1}$$

where l is a characteristic dimension of the food body, m, which is the radius for round shaped body and half of the thickness for a flat shaped body; h is the surface convective heat transfer coefficient, W/m^2 °C; and k is the thermal conductivity of foods, W/m °C.

There are:

- Bio ≤ 0.1, negligible international resistance to heat conduction,
- $0.1 <$ Bio < 40, finite internal resistance and external resistance, and
- Bio ≥ 40, negligible external resistance to heat convection (Singh and Heldman, 2001).

According to Eq. (16.1), the increase of air velocity will increase the value of h and thus the Bio number. For cooling or freezing of big food items such as beef with a big l value, a small air velocity should be used. Higher velocities can only lead to small reduction in the cooling time but require a large increase in fan energy and generate more extra heat load. For cooling or freezing of small food items such as peas, a high air velocity should be used. Air impingement, water spray or water immersion chiller can also be used to achieve a high surface heat transfer coefficient for small food items (Wang, 2008).

16.5.3.2 Application of novel refrigeration cycles Novel refrigeration cycles based on liquid-liquid absorption, liquid-solid adsorption and fluid ejection offer potential energy-saving opportunities for food refrigeration. An absorption-desorption cycle is based on the fact that the partial pressure of refrigerant vapor is a function of the temperature and concentration of a refrigerant solution. LiBr-H_2O and H_2O/NH_3 are two main working solutions used in absorption refrigeration cycles. An absorption refrigeration cycle has four main heat exchangers: generator, evaporator, absorber and condenser. High-temperature heat source is added in the generator to change the weak absorbent-refrigerant solution to a strong absorbent-refrigerant solution. Low-temperature heat from the product to be chilled is added to the refrigerant in the evaporator where the refrigerant becomes vapour and is absorbed

by the strong absorbent-refrigerant solution in the absorber. The heat of the cycle received is rejected to the outside of the cycle in the condenser and absorber. Adsorption is the transfer of molecules from a fluid phase to rigid adsorbent particles. Desorption is the separation of molecules adsorbed from the solid adsorbent particle. The key part of an adsorption refrigeration cycle is the working pairs such as zeolite-water or activated carbon-methanol (Wang et al., 1999; Choudhury et al., 2013). An ejector that can be used to replace the compressor in a mechanic refrigeration unit is a hydro-device with a special configuration and powered by a high-pressure jet of a fluid such as steam. In the ejector, a high-pressure jet of a fluid is used to entrain a low-pressure fluid from the evaporator and then increase its pressure for the condenser. Novel refrigeration cycles such as absorption and adsorption refrigeration cycles can be powered by low-grade waste heat or other renewable energy sources such as geothermal energy and solar energy at a low temperature (e.g., 70 °C) (Sun and Wang, 2001; Chen et al., 2013).

16.6 Summary

The food processing industry is the fifth biggest consumer of energy in the United States. Because of the increasing energy prices and efforts for reduction of CO_2 emission, it has become significant to improve the energy efficiency, replace the existing energy intensive unit operations with new energy efficient processes, and increase the use of renewable energy in the food industry. Energy efficiency improvement and waste heat recovery in the food industry has been a focus in the past decades. Replacement of conventional energy intensive food processes with novel technologies such as non-thermal processes may provide another potential to reduce energy consumption, reduce production costs and improve the sustainability of food production. Some novel food processing technologies have been developed to replace traditional energy intensive unit operations for pasteurization and sterilization, evaporation and dehydration, and chilling and freezing in the food industry. Most of the energy conservation technologies can readily be transferred from other manufacturing sectors to the food processing sector.

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17 Water Consumption, Reuse and Reduction Strategies in Food Processing

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17.1 Introduction

The total global water resources have been estimated to be about 1.4 billion km^3. The volume of freshwater resources constitutes only 2.5% of the total global water resources. As shown in Figure 17.1, less than 0.01% of the total global water resources (only 0.3% of the world's fresh water) is easily accessible for human beings and is in the form of lakes and rivers. This accounts for about 105 000 km^3 of water (WWDR, 2003). Actually, this figure demostrates very well how scarce our usable freshwater resources are, in spite of the fact that 70% of our planet is covered by water. Moreover, the pressure on the freshwater resources is growing incrementally due to the increasing population, urbanization and also improving economic prosperity.

Fresh water is a vital irreplaceable resource for the food processing industry, as it is a key processing element and a major ingredient in food processing. The problem of global water scarcity and the reduction in water availability enforce the food industry to put the issue of water management as one of the top priority items into its agenda to be able to ensure the sustainability of the industry. Different methods were proposed and used for measuring the water efficiency of the industry. The industrial water efficiency (also called the water withdrawal intensity), defined as the ratio of water withdrawn to the value of the industrial output obtained using this water, is a general indicator for the industry. The water recycling rate is the ratio of total volume of water recycled

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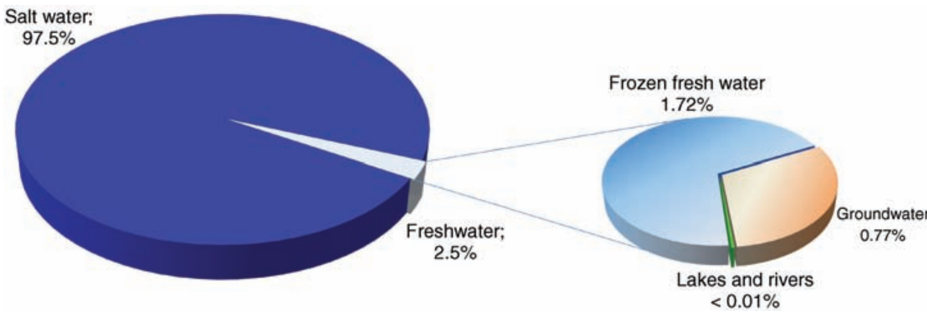

Figure 17.1 Global water resources.

in the establishment to the volume of water withdrawn. The organic pollution intensity is a measure of the wastewater production, and is defined as the total amount of organic pollutants discharged per unit of product (Maxime et al., 2006). The water footprint is a measure of the water use in relation to consumption patterns, that is it links up water use with the consumer. Hoekstra et al. (2009) defined the water foodprint of a product as 'the volume of freshwater used to produce the product, measured over the full supply chain'. Besides the volumes of water use and pollution, it also shows the location of the water use. The water efficiency is a major factor in determining the water footprint (WWDR, 2009). The concept of water footprint was first introduced by Hoekstra and Hung (2002). There are many countries like Japan and some European countries which, by importing water-intensive foods, have externalized their water footprints (Mekonnen and Hoekstra, 2011). Although it seems a wise strategy to protect their own water resources for these importing countries, it puts pressure on the water resources in the counter parties, namely the exporting regions. This may carry the global water problem to an almost unmanageable level in the long term, which eventually will definitely affect the importing regions as well. Therefore, it should not be forgotten that the sustainable use of water is a global issue and thus it should be handled and managed in a global manner rather than a national or regional level.

Industry is one of the main users of water. The industrial use of water increases with the level of income (Figure 17.2). Only 2% of the total freshwater withdrawals accounts for industrial use in low income countries, whereas the industry uses up to 43% of the total water in high income countries. It may account for as high as 69–75% of the total water use in some of the high-income countries such as Canada, France, Germany, United Kingdom and Switzerland (World Bank, 2011). The United Nations Environment Programme (UNEP) stated that Europe and North America are the two global regions where more water is used for industry than for agriculture (Henningsson et al., 2001). In Europe, 48% of the total water used is consumed by industry, whereas agricultural and domestic uses account for

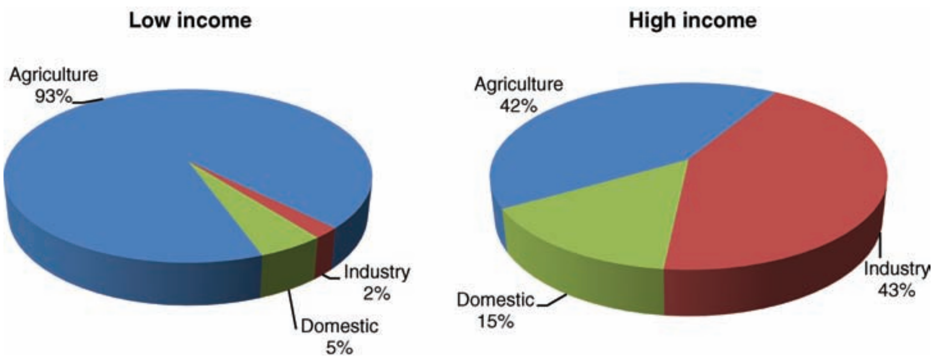

Figure 17.2 The dependence of sectoral breakdown of annual freshwater withdrawals to income levels based on the values for the year 2009. (Data obtained from World Bank, 2011).

38% and 14%, respectively (World Bank, 2011). The food processing industry is one of the most water intensive industries coming after the chemical and the rafinery industries. In Europe, the food industry has a share of between 8% to 15% of total industrial water use, which accounts for approximately between 1% to 1.8% of the total water use (CIAA, 2008). In Canada, the food and beverage industry use 6% of the water withdrawn and it is among the largest producer of industrial waste (Maxime et al., 2006). The annual water use of the food and drink industry is approximately 3000 Mm3/year in the UK (Cheeseborough, 2000) and approximately 215 Mm^3/year which accounts for 1% of the overall water use in Australia (Wallis et al., 2008). The food processing industry uses water in varying quality and quantity, for a range of purposes; a manufacturing ingredient, heat transfer vector, material exchange vector, mechanical energy vector, for washing and sanitation, and boiler feed as summarized in Table 17.1 (Maxime et al., 2006). It differs from other industries in terms of water quality demands, as the microbiological food safety is a major criterion for the food industry. Almost 70% of the total water use accounts for sanitation operations in some specific sectors within the food industry (Henningsson et al., 2004). Therefore, washing and sanitation operations are a major concern in reducing the total water consumption within the food industry. Cooling and heating operations ranks second with a share of about 20% of the total water consumed in the food industry. Although a proportion of the water used becomes a part of the food product, it is not higher than 20–30% even for the brewing and soft drinks sectors. Thus, in general, more than 70% of the total water used is discharged as effluent which is high in both biological oxgyen demand (BOD) and chemical oxygen demand (COD) levels, as well as in fats, oils and grease (FOG). Among the different industries, the food and beverage industry has the highest contribution to the emissions of organic water pollutants. Between 10 to 30% of the total industrial emissions of organic water pollutants comes from the food and beverage industry in high

Table 17.1 Water quantity and quality as a function of use by food and beverage industry. (Maxime et al., 2006. Reproduced with permission of Elsevier)

Water use	Relative quantity	Relative quality
Manufacturing ingredient: contact and mixing with other ingredients, initiation of reactions, preparation medium for sauces and soups, packing medium for certain canned foods, cooking broths and juices, major ingredient in beverages (non-alcoholic beverages from concentrate, beers) and ice cream and sorbets	Low to high (e.g. bottled water)	Potable; additional treatments possible, depending on the sensory properties desired for the finished product, or if involved in biological or microbiological reactions
Heat transfer vector: liquid or vapour, for thawing, reheating or conventional heat processing (blanching, pasteurization, sterilization, cooking). For condensation of vapour, cooling of equipment (compressors, pumps, fermentation tanks, pasteurizers, sterilizers, cans) or products (rinsing of vegetables with cold water), for freezing by immersion in brines. The water may or may not come into contact with the product, depending on the case	High	Intermediate to high–potable (if contact); softened water to limit scaling and deposits during cooling of containers; bactericidal activity for cooling of sterilizers
Material exchange vector (solvent): For extracting a solute from a solid (sucrose from beets), transferring a solute to a solid (candying, pickling, brining), extracting water (osmotic dehydration) or regenerating ion-exchange or adsorbent resins.	Medium to high	Potable; demineralised water for ion-exchange processes
Mechanical energy vector: transport of agricultural products (sweet corn, potatoes, beets), specific gravity separation in brine (potatoes, peas), cutting by hyperbaric water jet, disposal of waste that has fallen on the floor, removal of stains	Medium to high (transport)	Intermediate–potable (if contact); microfiltered water for water-jet cutting
Washing, cleaning and disinfection: washing and rinsing of food products, items that come in contact with foods during processes (equipment, pipes, bottles, metal cans, jars), and floors, walls and external surfaces of equipment	High	Intermediate–high–potable (if contact); softened water for rinsing containers
Boiler feed: production of process steam (thermal operations) or culinary steam (if direct contact with foods)	High	Softened–demineralised; degassing and pH correction necessary

Table 17.2 Industry shares of emissions of organic pollutants measured in terms of BOD (% of total) in 2007 (Data obtained from World Bank, 2011)

Country	Food and Beverages	Chemicals	Paper and Pulp	Textiles
Canada	14.0	10.9	8.9	7.3
France	16.6	15.0	7.4	4.8
Germany	11.4	12.4	7.1	2.4
Japan	15.0	11.2	7.0	5.3
New Zealand	31.1	8.6	12.2	5.8
United Kingdom	14.9	13.5	12.5	4.3
United States	12.0	13.1	8.1	4.3

income countries (Table 17.2) (World Bank, 2011). The BOD and COD levels in food processing industry wastewaters can be 10–100 times higher than those of domestic wastewater (FDM-BREF, 2006). The water and effluent fluxes within the food and beverage industry is given in Figure 17.3 (Maxime et al., 2006). Due to the high organic load and high COD and BOD demand, the effluents from food processing plants have an important impact on local water bodies. Initiatives at national and international levels are challenging the reduction of water consumption in the food industry, like the Food Industry Sustainability Strategy (FISS) of DEFRA (United Kingdom-Depatment for Environment, Food and Rural Affairs) which prospects for a 10–15% reduction in water use in the food industry by 2020 (FISS, 2006). The food safety

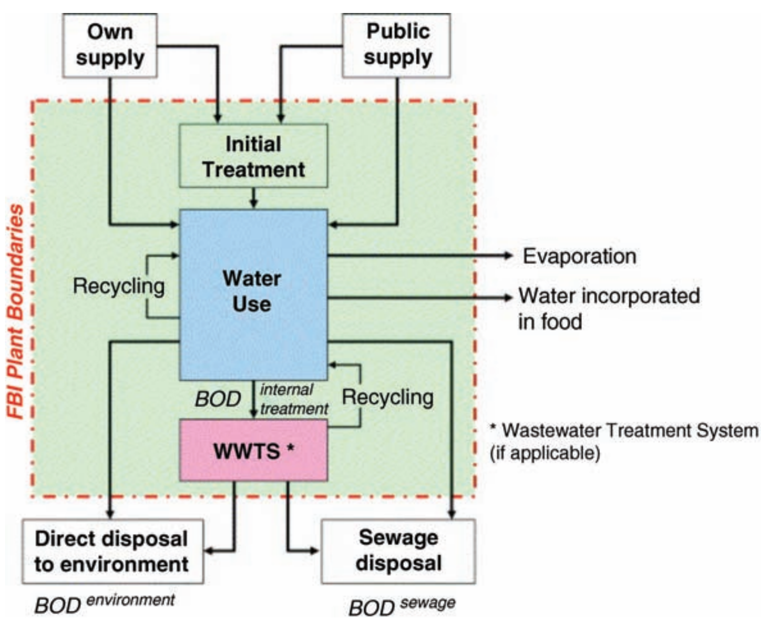

Figure 17.3 Water fluxes within boundaries of the food and beverage industry (Maxime et al., 2006. Reproduced with permission of Elsevier).

regulations represent a major barrier for the implementation of water conservation strategies in the food industry. The current regulations permit the processors to reuse or recycle water unless the water poses a risk for the product safety and the wholesomeness of the product in its finished form (Council Directvie 98/83/EC). The European Commission (EC) Council Directive 96/61/EC on Integrated Pollution Prevention and Control (IPPC) is laying down measures to reduce emissions in water resulting from a list of activities including meat, dairy and vegetable processing sectors. The indicative list of the main pollutants includes the organohalogen compounds, which are mainly associated with the use of chemical sanitizers. Therefore, sustainable use of water is one of the environmental challenges for the food industry and there is a need to develop eco-efficient innovative technologies that will aid a reduction in water consumption and wastewater generation rates, and improve wastewater quality in the food industry.

17.2 Sustainable water consumption

Water is a unique resource particularly for the food processing industry in that it has no alternatives. Reducing water consumption and ensuring the sustainable use of water is one of the major sustainable development priorities of the food industry. This is ultimately because overuse of water damages the environment and threatens the sustainability of water supply, and thus the sustainability of the industry itself. Due to the diversity of processing operations, the food industry uses a variety of water sources (groundwater, surface water, rainwater and recycled water) in differing levels for various operations. In general, sanitation operations account for most of the water use within the food industry. Two main focus areas for water management within the food industry are the efficient use of water, and the wastewater quality and management. The management of wastewater and wastewater quality is of the highest importance, because the main industrial impact on water resources is due to the highly polluted wastewater discharges rather than the amount of water used. The United Nations World Water Development Report 3 states that the global water withdrawals have tripled over the last 50 years, due to the growth in population, economy, urbanization as well as the technological changes (WWDR, 2009). On the other hand, the use of water by the processing industry declined as a result of both the technological developments and the intensive efforts put on mitigating environmental pollution during the last 50 years (Figure 17.4). Moreover, it is expected to continue to decline significantly in parallel to the developments especially in environmental technologies. About 1% per year of increase is foreseen for the water use efficiency of the processing industry (Flörke and Alcamo, 2004).

The sustainable use of water is an issue of global concern. Since today's industry is comprised of huge multinational companies which have factories all over the world, and since the legislations and policies regarding water management varies between countries, the cooperation of industry with the

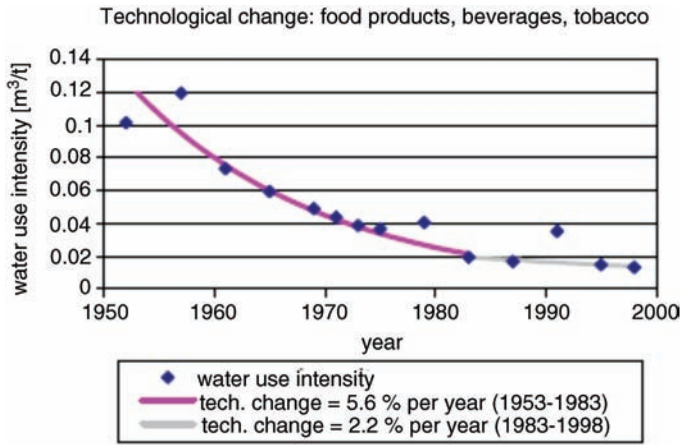

Figure 17.4 Determination of the historical technological change in water intensity of the manufacturing of food products, beverages and tobacco, considering two time periods (1953–1983 and 1983–1998). (Floerke and Alcamo, 2004. Reproduced with permission from the European Environment Agency).

local authorities and with governments is necessary for effectively managing the issue of sustainable water use. The cooperation of local and regional authorities with industry and the business sectors to optimize water efficiency and reuse for the realization of improved water management strategies and the protection of the local and regional water sources was also highlighted in İstanbul Water Concensus by the World Water Council during the Fifth World Water Forum in 2009 (İstanbul Water Consensus, 2009). During the last decade, some business initiatives have been developed in cooperation with the governments for sustainable water use in the food industry. An example is the DEFRA (United Kingdom Department for Environment, Food and Rural Affairs) Food Industry Sustainability Strategy (FISS) drawn up with the aid of the food industry stakeholders. It sets up measures and best practices for the sustainable development in food industry and targets a reduction of 10–15% of water use in the food industry by 2020 (FISS, 2006). Moreover, many food industry companies have started individual actions to assess their impact on water resources and to develop strategies on sustainable water use as a part of the companies' corporate social responsibility (CSR). Apart from the cost savings, ensuring the sustainability of the resources and thereby the industry, one of the main drivers in doing so is to maintain a good reputation in the market by contributing to global water sustainability (Lambooy, 2011).

There are also actions developed at international level for the sustainability of water. The UN Global Compact's (GC) 'CEO Water Mandate' was launched by the United Nations (UN) Secretary-General during the UN Global Leadership Forum in 2007 (CEO WATER Mandate-UNEP-GC, 2011). It aims to assist the development and implementation of water sustainability policies and practices in companies of all sizes and from all sectors all

over the world, by the endorsement of a company's Chief Executive Officer (CEO). The 'Global Water Tool 2011', first introduced by the World Business Council on Sustainable Development (WBCSD) in 2007, is a tool for companies to map and assess their water use and risks relative to water availability in their global operations and supply chains (WBSCD, 2011). The World Economic Forum in association with the United Nations Environment Programme (UNEP) launched the 'Water Initiative' in 2003. It focuses on creating multistakeholder networks to overcome bottlenecks and to facilitate the development of public-private water projects (WEF, 2008).

17.3 Water reuse in the food industry

The food industry standards necessitates that the process water intended for reuse should be at least of drinking water quality (Chmiel et al., 2002). The CODEX Alimentarius 'General Principles of Food Hygiene' states that:

> 'Water recirculated for reuse should be treated and maintained in such a condition that no risk to the safety and suitability of food results from its use. The treatment process should be effectively monitored. Recirculated water which has received no further treatment and water recovered from processing of food by evaporation or drying may be used, provided its use does not constitute a risk to the safety and suitability of food.' (CODEX Alimentarius, 2003).

The implementation of water reuse in the food industry needs special care and must be monitored carefully since it may bring food safety problems. Therefore, the implementation of safe water reuse strategies in food processing requires its integration into the HACCP programs (Casani et al., 2006; Kirby et al., 2003).

Water reuse targets three main issues: i) reduction of freshwater consumption, ii) minimization of wastewater discharges, and iii) achieving zero water discharge, meaning that the effluents will be reused after appropriate wastewater treatment methods, until no discharge is required. The cost effectiveness, water quality, operational complexity and regulatory compliance are major factors to consider for the assessment of the feasibility of a water-reuse system (Mann and Liu, 1999). Since cost is a decisive factor, the selection of the wastewater treatment methods should be based on the water quality requirements. Different levels of wastewater treatment are required depending on the quality of the wastewater effluent and the targeted end use, whether it will be reused or recycled, or will be discharged to the environment after the required discharge levels are met. The wastewater treatment processes may be divided into four categories according to the degrees of treatment: preliminary, primary (physico-chemical), secondary (biological) and tertiary (advanced) treatment (Pescod, 1992; Cheremisinoff, 2002). An overview of the unit operations at different levels used for wastewater treatment is given in Table 17.3 (Kirby et al., 2003). Preliminary

Table 17.3 Overview of representative unit processes and operations used in water reclamation (Kirby et al., 2003. Reproduced with permission of Elsevier)

Process	Description	Application
Solid/liquid separation		
Sedimentation	Gravity sedimentation of particulate matter, chemical floc, and precipitates from suspension by gravity settling	Removal of particles from turbid water that are larger than 30 μm
Filtration	Particle removal by passing water through sand or other porous medium	Removal of particles from water that are larger than about 3 μm. Frequently used after sedimentation or coagulation/ flocculation
Biological treatment (wastewater)		
Aerobic biological treatment	Biological metabolism of wastewater by microorganisms in an aeration basin or biofilm process	Removal of dissolved and suspended organic matter from wastewater
Oxidation pond	Ponds up to 1 m in depth for mixing and sunlight penetration	Reduction of suspended solids, BOD, pathogenic bacteria, and ammonia from wastewater
Biological nutrient removal	Combination of aerobic, anoxic, and anaerobic processes to optimize conversion of organic and ammonia nitrogen to molecular nitrogen (N_2) and removal of phosphorus	Reduction of nutrient content of reclaimed water
Waste stabilization ponds	Pond system consisting of anaerobic, facultative and maturation ponds linked in series to increase retention time	Reduction of suspended solids, BOD, pathogens, and ammonia from wastewater
Disinfection	The inactivation of pathogenic organisms using oxidizing chemicals, ultraviolet light, caustic chemicals, heat, or physical separation processes (e.g. membranes)	Protection of public health by removal of pathogenic organisms
Advanced treatment		
Activated carbon	Process by which contaminants are physically adsorbed onto the surface of activated carbon	Removal of hydrophobic organic compounds
Air stripping	Transfer of ammonia and other volatile components from water to air	Removal of ammonia and some volatile organics from water
Ion exchange	Exchange of ions between an exchange resin and water using a flow through reactor	Effective for removal of cations such as calcium, magnesium, iron, ammonium, and anions such as nitrate
Chemical coagulation and precipitation	Use of aluminium or iron salts, polyelectrolytes, and/or ozone to promote destabilization of colloidal particles from reclaimed water and precipitation of phosphorus	Removal of particles by sedimentation and filtration

(*continued*)

Table 17.3 (*Continued*)

Process	Description	Application
Lime treatment	The use of lime to precipitate cations and metals from solution	Used to reduce scale-forming potential of water, precipitate phosphorus, and modify pH
Membrane filtration	Microfiltration, nanofiltration, ultrafiltration	Removal of particles and microorganisms from water
Reverse osmosis	Membrane system to separate ions and particles from solution based on reversing osmotic pressure differentials	Removal of dissolved salts and minerals from solution; also effective for pathogen removal

treatment involves the separation of large particles in the wastewater to facilitate the subsequent treatment processes. Primary treatment methods involve physical methods of separation, such as filtration, sedimentation, flocullation, centrifugation and dissolved air flotation (DAF). They are applied to remove the settleable organic and inorganic solids (Palumbo et al., 1997). Primary treatment results in up to 50% reduction in biological oxygen demand (BOD_5), 70% in total suspended solids (TSS), and 65% in the oil and grease levels of the effluent (Pescod, 1992). Secondary treatment methods are used for the removal of biodegradable dissolved and colloidal organic matter based on biological treatment processes. They include mainly the activated sludge processes, trickling filters or biofilters, and rotating biological contractors (RBC) (Pescod, 1992; Palumbo, 1997). Subsequent application of the primary and secondary treatment processes results in the removal of 85% of the BOD and TSS of the wastewater. Tertiary or advanced treatment methods involves the use of chemicals for the separation, destruction or neutralization of contaminants associated with the wastewater (Cheremisinoff, 2002). They include mainly the disinfection technologies. Disinfection is the most critical step in treating water for reuse, as the microbiological safety of the treated water depends on the adequacy of disinfection. A comparison of the most commonly used wastewater disinfection technologies, especially in terms of their effects on changes in water quality is given in Table 17.4. According to the duration and level of use by the industry, the wastewater disinfection technologies can be classified into two groups: the mature technologies and the developing/emerging technologies (Leong et al., 2008). Among the mature technologies, the chlorination is still the most commonly used technique for wastewater disinfection. However, its use has been declining over the last few years due to the environmental and health risks posed by the use of chlorine. Mainly UV and to a lesser degree ozone have been replacing chlorine for wastewater disinfection over the last decade. Other than those listed here, there are some developing and emerging technologies, such as pasteurization, photocatalysis, ferrate and pulse UV.

Table 17.4 Wastewater disinfection technologies

Disinfection method	Advantages	Disadvantages
Chlorination and chloramination	Well-established Well-known inactivation mechanism Easiest Least expensive Residual effect for preventing post-treatment microbial growth	Efficacy pH dependent Formation of potentially carcinogenic DBP Increases chloride and TDS levels in final effluent Low concentrations of chlorine residuals may be toxic to aquatic life Low concentrations of chlorine residuals may be toxic to aquatic life Formation of halogenated DBP may enhance microbiological regrowth in reclaimed water distribution systems Formation of DBP toxic to aquatic life, i.e. cyanide Formation of potentially carcinogenic NDMA Requires final dechlorination before final discharge
Ozonation	Higher inactivation efficacy than chlorine Shorter contact times needed Reduces COD, turbidity, color, anthropogenic compounds and UV absorbance in effluent Increases disssolved oxygen levels in effluent No THMs and HAAs formation No harmful residuals Incidental removal of some contaminants	Formation of potentially carcinogenic bromate and other brominated DBP Unstable, requires on-site generation and monitoring, relatively difficult to operate Higher investment and operational costs No post-treatment residual effect
UV irradiation	Easy to operate No need to handle and store toxic and corrosive chemicals Short contact time needed Lack of toxic effect due to disinfectant residual in the effluent No THMs, HAAs, and cyanide formation Low potential for formation of other harmful DBP No effect on TDS levels	Potential risk of regrowth due to lack of residual effect Less effective against some viruses, spores and cysts Less effective for wastewater with low UV transmittance Higher operation and maintenace costs Mercury waste at the end of UV lamp life

(*continued*)

Table 17.4 (*Continued*)

Disinfection method	Advantages	Disadvantages
Chlorine dioxide	More effective to viruses than chlorine Efficacy less pH dependant than chlorine Less corrosive than chlorine and ozone Residuals degrade more rapidly than chlorine residuals Less impact on aquatic life compared to chlorine Residual effect for preventing post-treatment microbial growth Fewer potentially hazardous DBP formation than chlorine No THM formation in effluent More rapid decomposition of residuals Less impact of aquatic life Low investment cost	Formation of non-halogenated DBP and organic chlorine compounds Requires on-site generation and monitoring, relatively difficult to operate May produce noxious odors Higher operational costs Increases TDS and chloride levels in final effluent
Peracetic acid	Disinfection efficacy similar to chlorine Few or no harmful DBP formation Not create toxicity in effluents Similar or lower investment cost Adds organic carbon to effluent Some residual effect to control regrowth Principle end products are acetic acid, oxygen, water and carboxcylic acids Reduce odors in wastewater	Disinfection efficacy highly dependant on water quality Less effective against viruses and little effect on spores Risk of regrowth May from aldehydes, chlorine and bromine radicals if applied at high concentrations Unstable, requires on-site generation and monitoring, relatively difficult to operate Higher operational costs

TDS; total dissolved solids
NDMA; N-nitrosodimethylamine
THM; trihalomethane
HAA; haloacetic acid

The choice of the wastewater treatment method depends on many factors, such as the cost and feasibility of the system, the characteristics of the wastewater to be treated, the required effluent quality, the way of end use and the location of the plant (Pagan et al., 2004).

The dairy, meat and poultry, and the fruit and vegetable processing sectors are the major water-intensive sectors within the food industry (Table 17.5)

Table 17.5 Water consumption and wastewater generation rates in food industry (Data taken from FDM-BREF, 2006)

Sector	Water consumption (m^3/t)	Wastewater generation (m^3/t)
Fruit and vegetable	2.4–11	11–23
Meat and poultry	2–20	10–25
Dairy	0.6–60	0.4–60
Fish and seafood	3.3–32	2–40

*kg/unit of production

(FDM-BREF, 2006). Up to 90% of reduction in fresh water demand could be achieved by the reuse of process wastewater after treatment in some specific process operations during food processing (Table 17.6). The water consumption and wastewater volumes are in the range of 2.4–11 m^3/t and 11–23 m^3/t of product for the fruit and vegetable processing industry (FDM-BREF, 2006). The major points contributing to water consumption and wastewater stream in fruit and vegetable processing sector are: i) washing of raw and intermediate produce, ii) sanitizing activities in the processing plant, iii) blanching and fluming, iv) filling and cooling, v) moving the produce through the processing line. High volumes of wastewater are generated with high concentrations of organic materials. Therefore, the primary waste-management strategies used by this sector are water conservation and waste-solid separation (NCDENR, 2009). Carrying out the raw produce washing, grading and trimming operations at the field is recommended as an initial step in minimizing wastewater generation at the processing plant. Other practical approaches adopted by the industry include the use of air cooling instead of hydrocooling, replacing water blanching with steam blanching, use of multi-stage countercurrent washing systems, installation of high-pressure cleanup sytems for plant sanitation operations, reuse of water in another processing step and separating low- and high-strength wastestreams (NCDENR, 2009). The major wastewater parameters of concern in the fruits and vegetable processing sector are the BOD and the suspended solids. Moreover, the wastewater is high in sugars and starches, and contains residual levels of pesticides (FDM-BREF, 2006).

The water consumption and wastewater volumes in the meat and poultry processing sectors are in the range of 2–20 m^3/t and 10–25 m^3/t of raw material, respectively (FDM-BREF, 2006). The poultry pocessing industry has an average water consumption of 26 L of water per bird (Northcutt and Jones, 2004). The implementation of HACCP resulted an increase of approximately 5.4 L per bird in the average water consumption rates since it necessitates a specified minimum amount of water usage in some stages of the processing for assuring a targeted level of pathogen reduction. Eviscerating, cleaning and washing and chilling are the most water consuming steps in poultry processing. The wastewater from meat and poultry processing plants is significantly

Table 17.6 Examples of water conservation and effluent minimization practices for food processing industries

Processing industry	Description	Reduction in fresh-water demand (%)	Reduction in generated wastewater (%)	Reference
Poultry processing	Overall effect	12	10	Amorim et al., 2007
	Reuse of desensitization tank effluents for pre-washing of plastic transportation cages after preliminary treatment	12*	1*	
	Reuse of coolinf tank, cooling tunnel and storage chamber effluents in washnig the live poultry receiving and unloading yards	91*	9*	
	Reuse of effluent from final rinsing of cleaning operation for pre-washnig the by-product room	4*		
Poultry processing	Overall effect	34		Matsumura and Mierzwa, 2008
	Rational water use practices			
	Reuse; from pre-chiller after UF, from gizzard machines to viscera flume without pre-treatment, from freezing tunnel and frigofiric chamber after filtration	15 18		
Meat processing	Reuse of chiller shower water for warm cleaning after preliminary treatment, nanofiltration and UV disinfection			Mavrov et al., 2001
Dairy processing	Reuse of vapor condensate for boiler make-up after preliminary treatment, nanofiltration and UV disinfection			Mavrov et al., 2001
Dairy processing	Regeneration of single-phase detergents	75	75	Fernandez et al., 2010
Shrimp processing	Recycling water in peeling operation after treatment with reverse osmosis			Casani et al., 2006
Fruit processing industry	Reuse of spent process water from mixing and equalizing tank for boiler make-up, cooling, pasteurisation or bottle pre-washing after preliminary treatment, nanofiltration and UV disinfection	81		Blöcher et al., 2002

*effect on the specific operation described.

different from other food processing wastes in that it is polluted with high amounts of blood, skin and feathers, and includes high concentrations of proteins, fats, oils, grease and carbohydrates (Avula et al., 2009; Fonkwe et al., 2001). The protein content can be as high as 35%, which results in appreciably higher BOD and COD levels compared to the municipal sewage (Zhang et al., 1997). The USEPA (2004) states that the recycling of water in various stages of the poultry processing line is allowed on the condition that the reconditioned water maintains at least a 60% reduction in total microbial count where the reduction in coliform bacteria should be within 60% $\pm$ 10% limits. The joint implementation of rational water use strategies and economically feasible water reuse practices can aid in almost a 34% reduction in total water consumption in the poultry processing industry (Table 17.6) (Matsumura and Mierzwa, 2008). Avula et al. (2009) classified the methods used for reconditioning poultry processing wastewater into three categories; i) electrical and optical methods, or UV, ii) chemical and biochemical methods (e.g. ozone, chlorine dioxide, chlorine), iii) physical methods (e.g. dissolved air flotation, filtration). Although electrical stimulation can result in the inactivation of microorganisms, it has no clarification effect on the wastewater (Li et al., 1994). Similarly, ozone and chlorine dioxide have also been found to be efficient in reducing the microbial load of wastewater. Moreover, since ozone is capable of both inactivating the microorganisms and also oxidizing the organic matter present in the wastewater, it was found to be effective as a sanitizing agent in reconditioning of the chiller water overflow for reuse (Waldroup et al., 1993). Chilling is one of the four water intensive operation steps in poultry processing. Chiller overflow has a significant share in total water consumption in poultry processing (Mannapperuma and Santos, 2004). Therefore the reuse of a reconditioned chiller overflow is important in reducing the freshwater demand and wastewater discharge in poultry processing plants. Different types of screening systems (e.g. rotary screeens, shaker and bar type screens) are used to reduce the particulates in the poultry processing wastewater. The dissolved air flotation (DAF) method is employed for removing the suspended materials including fats, oil and grease (FOG) (McMahon, 2006). DAF units can reduce 30–90% of COD, 70–97% of TSS, and 89–98% of FOG in the meat processing wastewater (Johns, 1995; de Sena et al., 2009). Membrane filtration has an advantage over DAF due to its dual effect in wastewater reconditioning which includes both the removal of suspended materials including very fine particles as well as the separation of the microorganisms (Avula et al., 2009). Therefore, unlike conventional wastewater treatment methods after which the wastewater is discharged to the environment, membrane filtration technologies (e.g. reverse osmosis, nanofiltration, ultrafiltration, microfiltration) enable the reuse of wastewater in industrial processing (McMahon, 2006). Microfiltration using ceramic membranes or ultrafiltration by means of polymeric membranes may be applied for the reconditioning of chiller overflow. The latter was found to be economically

more feasible with an estimated pay back period of two and a half years for a 100 gal/min ultrafiltration system (Mannapperuma and Santos, 2004). The major water consumption sites in fish and seafood processing are equipment and floor washing, descaling, peeling, filleting, trimming and cleaning operations. For example, 80% of the wastewater generated and most of the COD content of the total discharge originates from the peeling operation in shrimp processing. Therefore, peeling is the major and most feasible source of water recyling in shrimp processing (Table 17.6) (Casani et al., 2006). The wastewater from fish and seafood processing plants is characterized by high organic load and tubidity, strong greenish colour and stinky odour (Afonso and Borquez, 2002a). The use of pressure-driven membrane processes, in particular ultrafiltration and nanofiltration, enable the recovery and reuse of fish processing wastewater and help to reduce the water demand of the industry (Afonso and Borquez, 2002b). Moreover, they aid in obtaining cleaner wastewater by reducing approximately 89–94% of the original COD content of the effluent (Lin et al., 1995).

The dairy industry consumes between 0.6 to 60 m^3 of water and generates between 0.4 to 60 m^3 of wastewater per ton of raw milk (FDM-BREF, 2006). The cheese processing is the highest water consuming and wastewater generating process. The dairy industry uses water mostly for sanitization, cooling and heating purposes. In order to be able to meet the required hygiene standards, high amounts of wastewater with high BOD, COD contents, FOGs and TSS is generated, and high levels of water and chemicals are consumed during the sanitization operations. Water consumption and wastewater discharge represent a major cost for the dairy industry. The water-to-milk intake ratio and the waste volume coefficient are the two indicators of water use efficiency for dairy processing factories (Milani et al., 2011). In Europe, the water-to-milk ratio ranges between 0.2 to 11 L/L milk, whereas in the Australian dairy industry it is between 0.07 to 2.90 l/l milk (Daufin et al., 2001). The implementation of sustainable water management practices through the recycling and reuse of water is important in terms of minimizing production costs and the environmental impact of the dairy industry. However, there are some constraints for the reuse of water in dairy plants as in other sectors of the food industry. The CODEX Alimentarius Code of Hygienic Practice for Milk and Milk Products necessitates that the reuse water

> ‘should be treated and maintained in such a condition that no risk to the safety and suitability of food results from it use’
> and that
> ‘reconditioning of water for reuse and use of reclaimed, recirculated and recycled water should be managed in accordance with HACCP principles’ (CODEX Alimentarius, 2004)

The development of new membranes with high flux/rejection characteristics improved the potential for water reuse and recycling within the dairy industry

(Sarkar et al., 2006). The use of single-phase detergents, which combines the acid cleaning, alkaline cleaning and disinfection stages during sanitation operations, helps to reduce the amount of water and chemicals needed, as well as the energy input in the dairy industry. Regeneration of cleaning solutions using membrane technologies is another approach for reducing water and chemical demands, and wastewater generation within the dairy industry (Fernandez et al., 2010). Membranes with different pore sizes (microfiltration, ultrafiltration, nanofiltration) can be used for this purpose, depending on the COD content of the feed solution and the cost of the operation (Gesan-Guiziou et al., 2007; Kaya et al., 2009; Boussu et al., 2007). Fernandez et al. (2010) reported a recovery ratio (RR) of 75% for water and detergents through the application of nanofiltraton for the purpose of recovering the single-phase detergents (Table 17.6). Enzymatic cleaners aid in decreasing the amount of inorganic cleaning agents and result in an easier to treat wastewater effluent and thus offer great potential in reducing the environmental impact of sanitization effluents from dairy factories (Grasshoff, 2002; Arguello et al., 2003). The implementation of the reverse osmosis (RO) membrane technology enables the recovery and reuse of water from milk and thus reduces the water demand of the milk processing plants (Baskaran et al., 2003). Nanofiltration of cheese whey reduces the water demand by allowing the recovery of approximately 80% of water, and results in the generation of a cleaner wastewater with lower organic load (Minhalma et al., 2007). Vourch et al. (2008) demonstrated 95% recovery of dairy processing wastewater by reverse osmosis to be reused for heating, cooling and cleaning operations.

17.4 Water consumption reduction strategies

The industrial water management strategies can be classified into two groups: internal strategies and external strategies (Grobicki, 2008). The main components of increasing industrial water efficiency are: 1) water auditing, 2) reuse and recyling, 3) reclamation, 4) implementation of best practices, and 5) investment to water-efficient technologies (Grobicki, 2008; CIAA, 2008). These can be collectively defined as internal strategies, since they all are measures that should be implemented at a factory level. By definition, water reuse is defined as the use of water in more than one process where progressively lower quality of water is needed, whereas recyling refers to the return of water to the same process for multiple use after treatment. Water reclamation, reusing wastewater produced elsewhere after being appropriately treated, is another element of increasing industrial water efficiency. Further to these, there are external strategies which should be managed at a national level and implemented at the industry level. The national water conservation policy is a key determining factor for external strategies. They include both regulatory policies such as gradually increasing water fees for increasing volumes of water used, applying specific water conservation taxes on operations using higher than a specified amount of water,

pre-requisiting approval from local authorities for new factories anticipating more than a threshold level of water consumption monthly or annually, and well targeted economic incentives like tax incentives, or the subvention of industries for the implementation of water efficient environmental technologies (Grobicki, 2008). These types of regulatory and economic measures are effective in promoting the take-up of environmental technologies, and encouraging the industry to initiate and implement internal water management strategies. Proper implementation of internal water management strategies is highly affected by the economic incentives. Sanchez et al. (2011) reported that costs associated with water supply and effluent discharge are important factors in making desicions about investing in water recycling and wastewater treatment systems. Therefore, stringent environmental regulations will play an important role in enhancing the development and utilization of eco-innovative technologies for sustainable water consumption.

The major problem of the industry in terms of water conservation is the lack of knowledge or data on the volumes of water used and discharged at specific steps of the processing line. A systematic approach for water management could lead to about 30–50% decrease in total water use. The implementation of a systematic water consumption reduction strategy is only possible if a thorough water audit could be conducted to target the quantitative and qualitative water quality requirements to the particular process, where and how much water is used and what quality of water is actually needed in each processing step (ETBPP, 2000; Kirby et al., 2003). This type of systematic approach for identification of areas with high water consumption and wastewater discharge will enable these target sites to be focused on so that susbstantial water savings can be achieved simply by reducing uncontrolled and unnecessary use. A flow chart demonstrating the water balance on the plant and on individual processing steps should be the reference document for carrying out a water audit. Then, water use can be monitored to track the progress of conservation. Matching water quality to the actual needs of the process should be a major component of a water consumption reduction strategy (Grobicki, 2008). Since food safety is the major criteria in processing, this requires an analysis and evaluation of the potential contamination sources for the processing line and the product itself and therefore it should be integrated into the HACCP plans in food factories. The application of HACCP into water reuse systems can be regarded as a quantitative risk management system which increases the safety of the reuse water. Moreover, the systematic and preventive approach of HACCP also contributes to reducing the cost of the process, obtaining a higher quality wastewater and a reliable evaluation of the wastewater treatment process ((Huertas et al., 2008). Casani and Knochel (2002) developed a HACCP based generic model for the implementation of water reuse in the food industry (Figure 17.5). This model consists of two main groups of steps: the preliminary steps refer to the definition of the HACCP team and implementing a water audit, in general.

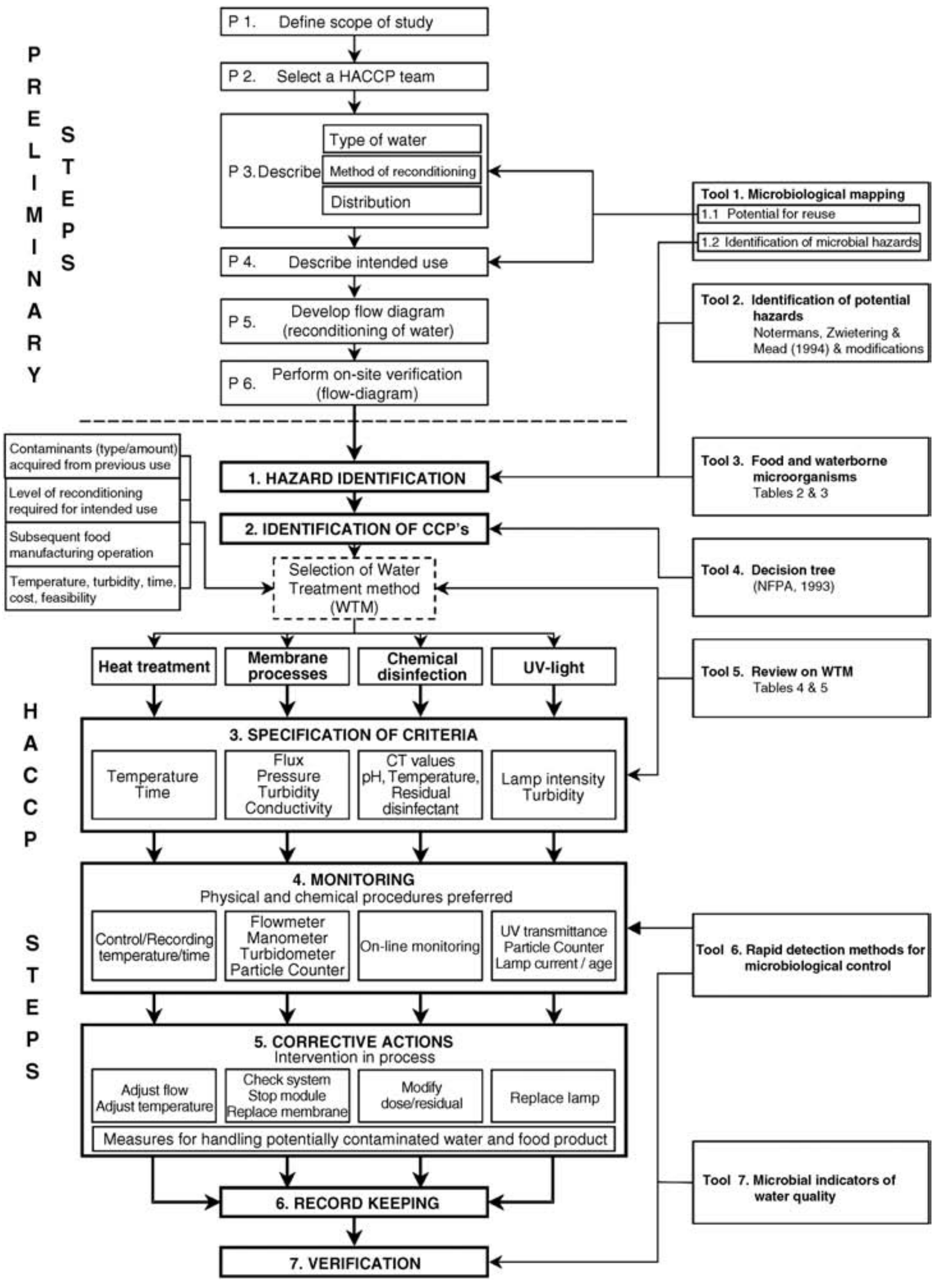

Figure 17.5 Scheme for establishing a HACCP plan for reconditioning of process water to be reused in the food industry (Casani and Knochel, 2002. Reproduced with permission of Elsevier).

The second step is the implementation of the seven principles of the HACCP system. The establishment of such an HACCP plan will enable the determination of safe water recycling, reuse and reclamation opportunities, which are actually the primary means of saving water in industrial applications.

Compared to the other components of increasing industrial water efficiency, the implementation of best management practices is the easiest achievable target with minimum investment, whilst it may have a substantial impact on water conservation. These may include simple measures to increase the water efficiency in the factory, such as personnel training and awareness raising on water conservation, modifying the routine cleaning plans, maintaining the processing lines to prevent leakages, using hand-controlled triggers on hoses and sensor controlled taps and careful and hygienic design of equipment (CIAA, 2008; FDM-BREF, 2006). Up to 30% reduction in water consumption can be achieved by these types of simple measures (Kirby et al., 2003). In general, the water consumption reduction strategies through simple measures and operational modifications specific for the food industry include the use of (Pagan et al., 2004; Casani et al., 2005; FDM-BREF, 2006; Napper, 2007):

- Easy to clean conveyor belt like V-shaped rollers.
- Automatically controlled spray rinsing and overspray foggers instead of typical overflow systems.
- Multi-stage counter-current flow systems which consume up to 50% less water as compared with the conventional single-step washing system.
- Flow restrictors to maintain the optimum water flow rate.
- Trigger operated controls for hoses.
- Segregating effluents with different wastewater characteristics to reduce the overall pollutant load and allow for the optimization of reuse of water and treatment needs.
- Removing organic material from the process water at the point where it is first introduced to water, before the progress of bacterial growth and before it is mixed with other contaminants.
- Dry pre-cleaning prior to washing.
- CIP systems allowing for storage of rinse water and the recovery of chemicals for use.
- CIP systems employing pulsed rinses.
- High pressure low volume washing systems.
- Pneumatic or mechanical conveying systems instead of hydraulic systems.
- Steam blanching instead of water blanching.
- Vacuum thawing, air blasting or still air instead of open tubs of water for thawing.
- Air blast cooling instead of water cooling.
- Dry peeling instead of wet peeling.

Since cleaning and sanitizing accounts for almost 70% of the total water use within the food industry, reducing the volume of water used for these

operations would have an important impact on reducing the water demand of the food industry. Both for the disinfection of product and the equipment surfaces, more water efficient disinfection techniques which have less environmental impact, such as ozone, UV, ultrasound, enzymes or electrolyzed water can be used as an alternative to chlorine. A comparison of the disinfection methods proposed for fresh-cut vegetables are given in Table 17.7 (Ölmez and Kretzschmar, 2009). As the amount of wastewater generated per unit mass of product is dependant on the disinfection technique employed, techniques capable of disinfecting both the process water and the product efficiently would allow a high ratio of recycling and thereby would reduce the wastewater rates and would have a lower impact on the environment. Moreover it is also important to consider the formation of toxic or harmful DBP, level of antimicrobial activity and the contact time needed which determines the length of process, and of course the cost factors.

The use of clean-in-place (CIP) systems and the regeneration of cleaning solutions using membrane technologies are important elements of the water reduction strategy in the food industry. The CIP systems allow the equipment, tanks and pipes to be cleaned without being assembled, enable the recirculation of rinse water and cleaning chemicals, and thus help to reduce both the water and the chemical consumption up to 50% (Pagan et al., 2004). The regeneration of cleaning solutions results in reduced demand for water, energy and chemicals (Mawson, 1997; Fernandez et al., 2010). Microfiltration, ultrafiltration and nanofiltration are the most commonly used membrane processes for this purpose. The economic and technical feasibility of the membrane processes for recycling chemicals depends on many factors; regulatory requirements regarding the reuse of solutions and wastewater disposal, cost of water and wastewater disposal, the characteristics of the cleaning solution, temperature of the cleaning solution, the stability and the flux and fouling behaviour of the membrane used and the recovery ratio (Mawson, 1997).

Due to high levels of salt, protein and possibly microorganisms, the disposal of brines is a major issue for the food industry, specifically for the cheese, meat and fish processing sectors. One of the main problems with brine disposal is that when it combines with other waste streams in the processing plants, it becomes impossible to treat the final effluent (Mawson, 1997). Membrane technologies are also shown to be effectively used for the purpose of brine recovery in different sectors of the food industry resulting in significant reductions in wastewater discharge and associated costs. Ultrafiltration and microfiltration, which enable the long-term reuse of brine, have been applied for brine recycling in cheese manufacturing (Honer, 1990; Russel, 1994; Skrzypek and Burger, 2010), for the recovery of chilling brines in meat and fish processing (McGinnis et al., 1990; Hart et al., 1988) and olive processing (Rejano et al., 1995).

Zero water discharge, *meaning that all the wastewater effluents that would normally be discharged to the environment is treated, recycled or sold to other*

Table 17.7 Advantages and limitations of disinfection methods proposed for fresh-cut organic vegetables (Ölmez and Kretzschmar, 2009. Reproduced with permission of Elsevier)

Disinfection method	Advantages	Limitations/Disadvantages
Chlorine (Hypochlorite)	Low cost Easily available	Hazardous DBP at high levels Reacts with organic matter Efficacy is affected by the presence of organic matter Corrosive Activity pH dependant Not allowed for organic products
Ozone	High antimicrobial activity Short contact time GRAS substance No residue problem No hazardous DBP formation No need to store hazardous substances Lower running cost	Requires on-site generation Toxic when inhaled Requires monitoring in indoor applications Corrosive above 4 ppm Higher initial investment cost Not allowed for organic products
Chlorine dioxide	Higher antimicrobial efficacy at neutral pH than chlorine Effectiveness less pH dependant than that of chlorine Fewer potentially hazardous DBP formation than chlorine Less corrosive than chlorine and ozone	Not efficient at permitted levels for fresh produce Requires on-site generation Explosive Only allowed in whole produce Final water rinsing is required after treatment More iodinated DBP formation than chlorine if iodide exists in water Formation of specific by-products, chlorite and chlorate Requires monitoring in indoor applications Not allowed for organic products
Organic acids	Easy to use No toxicity Allowed for organic products	Long contact time, not relevant to the industry Interferes with the sensory quality Relatively lower antimicrobial efficacy Not allowed for organic products
Peroxyacetic acid	Efficacy is not affected by the organic load of water Efficacy unaffected by temperature changes No harmful DBP formation Not corrosive at permitted levels (<80 ppm)	Low antimicrobial efficacy at permitted levels for vegetables Not allowed for organic products
Hydrogen peroxide	No residue problem Easy to use Low cost	Low antimicrobial efficacy Long contact time Phytotoxic, negative impact on overall quality Requires the removal of residual H_2O_2 after processing Not allowed for organic products

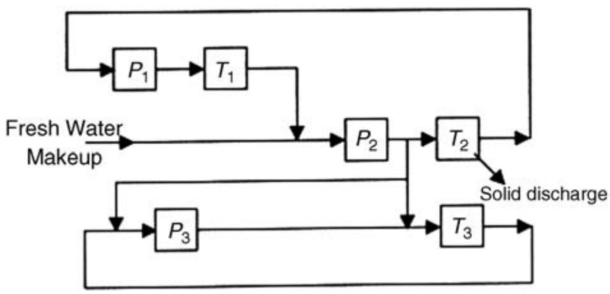

Figure 17.6 A zero liquid discharge scheme (Bagajewicz, 2000. Reproduced with permission of Elsevier).

users, is a key target of the industry for sustainable use of water (Figure 17.6) (Gorbicki, 2008; Bagajewicz, 2000). It is a concept to minimize the fresh water consumption in single- or multi-contaminant systems in the industry (Koppol et al., 2003). It can be handled either at the factory level, at the local level or at a municipality level. Various approaches were developed for the feasibility assessment and optimization of zero water discharge and water minimization systems in the industry. Different types of techniques are applied to continuous and batch processing systems mainly owing to the differences in the time dimension. As shown in Figure 17.7, the water utilization in continuous systems may consist of: i) a single wastewater stream coming from a series of sequential processing operations (Figure 17.7a), ii) the reuse of wastewater from one processing operation to feed another operation without any treatment (Figure 17.7b), iii) the use of series or parallel designs for the treatment of different kinds of wastewater streams separately from different processing operations (Figure 17.7c), or (iv) decentralized treatment systems

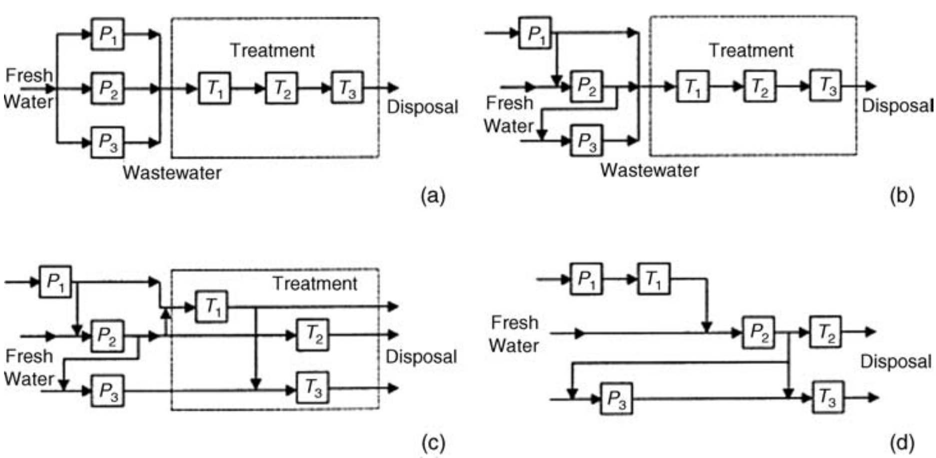

Figure 17.7 Water utilization systems in process plants (Bagajewicz, 2000. Reproduced with permission of Elsevier).

(Figure 17.7d) (Bagajewicz, 2000). The two main approaches used in continuous systems are the mathematical programming (Boix et al., 2011; Koppol et al., 2003) and the conceptual (insight based) design techniques including the 'water pinch technology' (Zheng et al., 2003; Feng et al., 2008). Mathematical programming procedures, namely the mixed integer linear (MILP) and non-linear programming (MINLP) models were performed for water minimization both in single- and multi-contaminant systems (Savelski and Bagajewicz, 2000a; Savelski and Bagajewicz, 2003; Koppol et al., 2003; Boix et al., 2011). In spite of the advantages in accuracy and computational effectivenes in handling complex multiple contaminant systems, the mathematical programming approach is less commonly used owing to the difficulty in applying the methods and setting up the models. On the other hand, the conceptual design techniques are easier to apply and do not need a knowledge of mathematical optimization techniques, but they lack computational effectiveness and often optimality (Manan et al., 2009). Pend et al. (2001) reported a reduction of 60% in fresh water use and correspondingly wastewater discharge as well as a significant reduction in contaminant loads in a dairy plant by the application of water-pinch analysis (WPA). Due to the complimentary nature of these two approaches, the use of hybrid models, that is using the conceptual approach to build models for mathematical programming is regarded as a more efficient approach for providing optimal solutions (Bagajewicz, 2000; Boix et al., 2011). Further to this, as a newer approach some researchers used a combined numerical and graphical tool for the simultaneous water and energy reduction (SWE) in processing plants (Manan et al., 2009; Dong et al., 2008; Kim et al., 2009; Feng et al., 2009). Manan et al. (2009) reported a reduction of 13.4% in fresh water consumption achieved using the SWE reduction method in a paper mill plant. They used a three-step SWE analysis: i) setting minimum targets for water and wastewater, ii) the design of minimum water uitilization network using the improved cleanest to cleanest rule, iii) the design of energy recovery (Figure 17.8) (Manan et al., 2009).

Relatively less work has been done regarding the water minimization techniques in batch processes compared to the continuous processes. In general, the batch processes are more difficult to design due to the discreteness of the tasks and the time dependence (Gouws et al., 2010). As shown in Figure 17.9, the water utilization in a batch system may consist of either a truly batch operation (Figure 17.9a) or a semicontinuous operation (Figure 17.9b). The same approaches, namely the conceptual design approach and the mathematical modelling approach, but with different specific techniques are used for water minimization in batch systems. The difference of conceptual design approaches used for batch systems and continuous systems is that the former also includes the time constraints together with the concentration constraints. They include the graphical targeting (Wang and Smith, 1995; Chen and Lee, 2008; Majozi et al., 2006) and algebraic targeting techniques

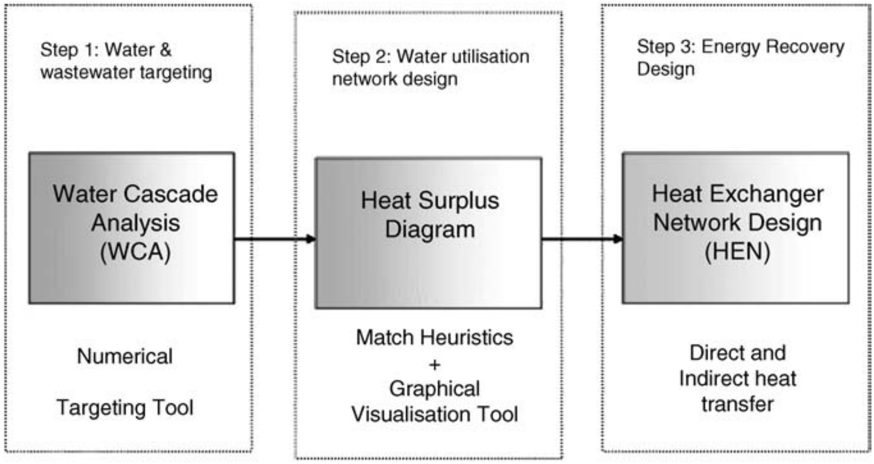

Figure 17.8 Three-step procedures for SWE minimization (Manan et al., 2009. Reproduced with permission of Elsevier).

(Foo et al., 2005; Liu et al., 2007). The mathematical techniques are divided into two main groups depending on whether time is taken as a parameter or as a variable (Gouws et al., 2010). The former technique minimizes water flows in a fixed schedule (Kim and smith, 2004; Chen et al., 2008) whereas the latter ones are used to determine the schedule with minimum water flow (Majozi and Zhu, 2001; Cheng and Chang, 2007). Hybrid methodologies, combining graphical and mathematical techniques are also used for minimizing water use in batch systems. Oliver et al. (2008) used water pinch analysis with MILP to optimize water use in batch processes in a winery and achieved a theoretical freshwater reduction of approximately 30%. However, unlike the continuous systems, the simultaneous optimization of water and heat is an area for future work, like the simultaneous water minimization and scheduling in multi-contaminant batch systems (Gouws et al., 2010).

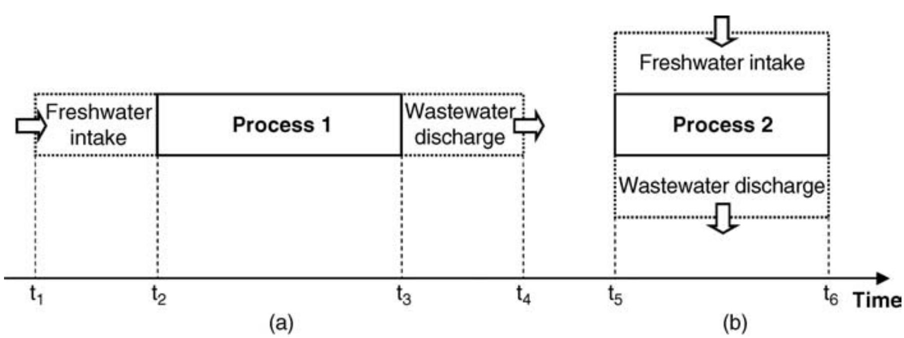

Figure 17.9 Types of batch water using processes: (a) truly batch, (b) semi-continuous (Gouws et al., 2010. Reproduced with permission of the American Chemical Society).

17.5 Challenges and opportunities

Casani et al. (2005) discussed the challenges facing the food industry in improving its water efficiency: i) environmental issues, ii) cost, iii) regulations, iv) technological issues, v) food safety, vi) water quality, vii) social issues and viii) research (Table 17.8). One of the main challenges facing the food industry in assuring its sustainability is the development or adaptation of eco-innovative

Table 17.8 Drivers, barriers, challenges and solutions to implementation of water reuse in the food industry (Casain et al., 2005. Reproduced with permission of Elsevier)

Issues	Drivers	Barriers or problems	Solutions and challenges
Environmental	Growing demand for water Limited access to water in some areas Increased concern about the impact of industrial activity on the environment	Population growth and increasing life standards	Water demand management
Economical	Increasing costs for fresh water Increasing costs for wastewater discharge	Companies look for short payback times False perception on company's water costs being low Accounting systems unable to measure the true cost of using water	Calculations based on true cost of water
Legislation	Open to the use of alternative water qualities	Standards versus guidelines	Guidelines: risk-benefit approach, adaptation to food sector and case by case approach
	Possibility of lowering requirements without resulting in significant health risks	Complex and demanding process	Need for guidelines
		Regulations are too strict and not flexible	Determination of the minimum required quality
	Strict wastewater quality discharge regulations	Lack of relevant training among regulators	Need to focus on relevant aspects, e.g., risk assessment Promote and support R & D on water reuse Promote collaboration with scientists and food processors

Table 17.8 (*Continued*)

Issues	Drivers	Barriers or problems	Solutions and challenges
Technological (Treatment)	Availability of technically feasible purification processes	Lack of guidelines for process water treatment	Development of a set of relevant criteria for assessment of performance and comparison
		Demanding procedures for quality control of processes	Documentation of fail-safe measures
		Lack of easy access to evaluate different methods	Development of reliable methods for assessing efficiency of treatment
			Studies on microbial resistance to water treatment methods
	Commercial use of by-products after treatment		Application of HACCP for handling of concentrates
Water quality assessment	Need for reliable methods	Reluctance to change parameters and methods	Need for identification of new and reliable indicators
		Unclear relationship between indicators and health	Research on this topic
		Indicators not being a direct index of safety	Case by case assessment
		Current methods are only suited for verification purposes	R & D of on-line methods
		How to guarantee adequate water quality	Implementation of risk assessment and HACCP
Social	Water scarcity	Negative perception and acceptance for water reuse	Promote communication between scientists, media and consumers
Food industry	High water consumption	Water reuse is considered a luxury	Motivate and educate personnel
	High wastewater generation	Water reuse requires testing and documentation	Disposal of resources
	Potential for water reuse within factories	Complex implementation of water reuse practices	Implementation of safety and quality tools to handle water reuse
			Collaboration with regulatory agencies and research institutions
Academia			Open-mind for applied research in collaboration with industry

processess that will diminish the negative impacts of the food industry on environment and on natural resources, especially on water. Minimization of water consumption and wastewater discharge in the food industry could be achieved by replacing the water-based technologies with 'water-free technologies' where possible and by the implementation of a well established systematic approach in water consumption reduction during processing. However, there are several hindrances to increasing water efficiency in the food processing industry. The first is the cost, in terms of the time and investment, needed to implement a water management plan. The second is the low water prices, which on a cost-profit basis, makes it unjustifiable to invest in water management systems (Wallis et al., 2007). Technological developments are a critical opportunity for increasing the water use efficiency of the food industry. Depending on the industry, it is expected that, 25–36% decrease in the water use of the industry will be achieved by 2030 due to the technological developments in the water intensive industries (Flörke and Alcamo, 2004). Therefore, it is important that the governments support technological improvements directed towards water efficiency in industry. This should include both support for investing and adopting water efficient technologies by the industry, as well as supporting research on every aspect of this area. The industrial grant programmes can be incentives for encouraging the industry to invest in water efficienct technologies. The European Union Environmental Technology Action Plan (ETAP) launched in 2004 and the following Eco-innovation Action Plan (EcoAP) build on the ETAP in 2011 are examples of union level initiatives. They are aimed at coping with the barriers faced by the industry in the uptake of eco-innovative technologies and provide some incentives for the industry to use environmental policy and legislation as a driver to promote eco-innovation, by developing new standards boosting eco-innovation, by introducing some financial instruments and support services for SMEs, and by promoting international cooperation (EC EcoAP, 2011).

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18
Food Industry Waste Management[1]

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It has been acknowledged that the global food system produces an enormous amount of waste from both packaging and processing of food resulting in a significant global problem with serious economic, social and environmental implications (Parfitt et al., 2011). Estimations indicate that approximately 25% of material that is introduced into the supply chain is wasted (Dobbs, 2011; Green and Johnston, 2004; Gustavsson et al., 2011). Furthermore, it has been estimated that up to 25% of the food sent to landfill by the food manufacturing and retail industries is either edible or could be turned into compost or energy (Green and Johnston, 2004). This implies that opportunities for improvement in waste management practices are significant.

This chapter is devoted to the analysis of the types of waste we can find in the food supply chain, the main causes of waste generation, what the current practices for waste management are and what is being done to try to reduce the quantity of waste that is currently being ineffectively managed. This chapter is divided into six sections. In the first section we provide a definition of food waste and present evidence about the scale of the problem. The second section takes a supply chain perspective and describes the key stages in the food supply chain and how each contributes to waste. We then continue by

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discussing what happens to waste and Section 4 looks into the causes of waste in Section 3. Section 5 describes possible solutions to the food waste problem and finally, Section 6 presents the concluding remarks.

18.1 What is food waste?

Waste has been defined as ' . . . any substance or object the holder discards, intends to discard or is required to discard' (European Commission, 1991). Other definitions take a broader perspective; for instance the term *Muda*, which is Japanese for waste, is often used to refer to seven types of waste: overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary motions and defects (Bicheno, 2004; Womack and Jones, 1996). While these types of waste are legitimate concerns, the problem of physical waste is large and complex enough to merit dedicated attention.

Food waste includes cooked or raw materials that are discarded at any stage between the farm and the consumer. It can be divided (see Table 18.1) into avoidable, for example, slices of bread, meat, and so on, and unavoidable streams (Lebersorger and Schneider, 2011). Unavoidable waste mostly comprises inedible parts of raw food (preparation residues such as bones, egg shells, or, for example, fruit and vegetable produce with inedible skin/peel and trimmings that will cause waste if it is to be prepared into a 'ready to eat product'). Some classifications also include 'possibly avoidable waste', as some foods, such as potato skins, bread crusts, and so on, are not unanimously considered to be edible (WRAP, 2009).

Another classification of waste that applies exclusively to animal by-products was introduced by the European Union in 2003 and categorizes waste into three types (European Commission, 2002):

- Category 1: High risk to be incinerated.
- Category 2: Materials unfit for human consumption. Most types of this material must be incinerated or rendered.
- Category 3: Material which is fit for but not destined for human consumption.

Table 18.1 Classification of food waste based on Lebersorger and Schneider (2011) and WRAP (2011)

Non avoidable	Preparation residues
Possibly avoidable	Preparation residues
Avoidable	Leftovers
	Whole unused food
	Part consumed food

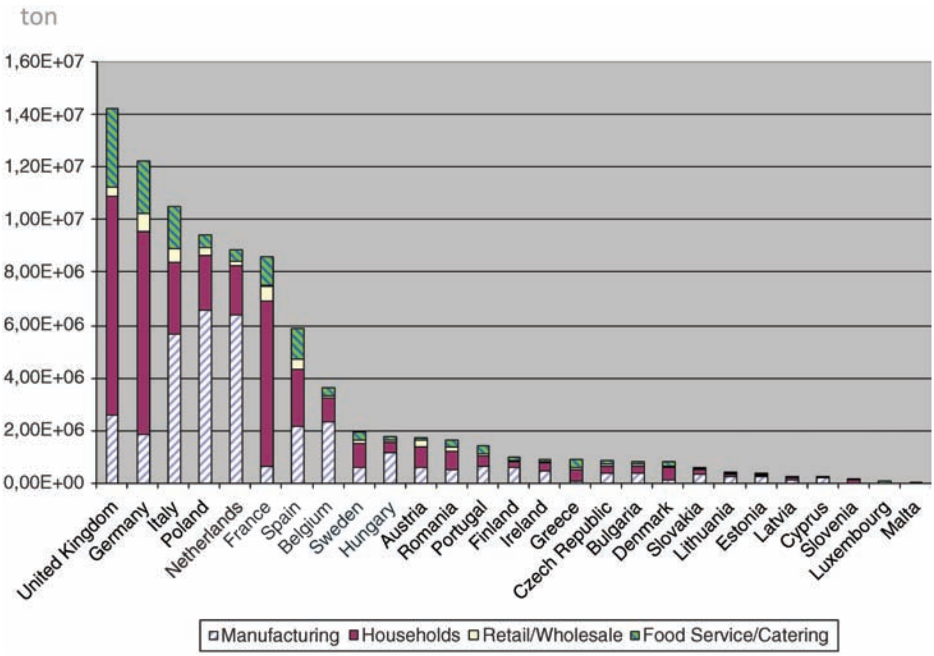

Figure 18.1 Tonnes of total food waste generation in manufacturing, household and catering in EU27 during 2006 (European Commission, 2010).

The scope of the problem on a global scale is difficult to quantify because there is no homogeneous way of measuring waste across different stages of the food supply chain. However, it is known that volumes of food waste vary widely by country. In the USA, 27% of all the edible food available for human consumption in 1997 is estimated to have been wasted, two thirds of that being fruit, vegetables, milk, grain and sweeteners (Kantor et al., 1997).

In EU27 (European Union of 27 countries), it is estimated that the 2006 annual food waste generation was about 89 Mt and is expected to be a total of 126 Mt in 2020 (see Figures 18.1 and 18.2) (European Commission, 2010).

18.2 The food supply chain

The food and drink sector plays an essential economic and social role. In developing countries it is estimated that around 40% of the world's labour force is employed in agriculture alone (CIA, 2011). In developed economies such as the USA, Europe and Japan this figure is considerably lower (circa 10%). However, the food industry continues to play an important economic role in these countries too (CIA, 2011; Defra, 2011). For instance, in the UK the food and drink sector accounts for 7% of GDP, employing 3.7 million

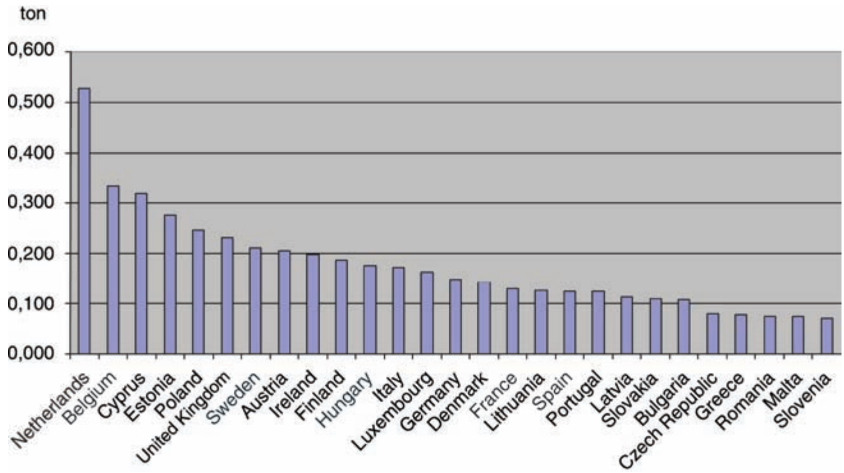

Figure 18.2 Per capita tonnes of total food waste generation in EU27 during 2006 (based on European Commission, 2010).

people. In an average UK household, 9% of income is spent on food, reaching 15% in the case of the poorest 10% of families. The percentage of income spent has been declining since the 1950s, but recently the trend has reversed (Caswell, 2008). The British government therefore decided to create the Waste & Resources Action Programme (WRAP), an agency dedicated to helping individuals and businesses to reduce waste and recycle more, and currently WRAP is the leading UK research organization on food waste.

It has been estimated that the value of global agricultural output has grown at an average rate of 2.3% per year since 1961, outpacing the average population growth during the same period which was 1.7% per year (FAO, 2007). The World Bank predicts this trend will continue and that by 2030, world demand for food will be 50% higher than in 2009 (Evans, 2009). Growth comes mainly from large, developing countries such as India, China, Brazil and Nigeria (FAO, 2010). Nevertheless, growth rates in both production and consumption of food have slowed down due to the financial crisis in 2009 and 2010 (FAO, 2010).

Despite all its social and economic benefits it can provide, the food industry manufactures products that have negative impacts on public health causing issues such as malnutrition, foodborne diseases and obesity, as well as on the environment in the form of pollution, use of natural resources, Greenhouse Gas (GHG) emissions and waste.

The food and drink supply chain is a complex network of organizations that is continuously adapting to changing circumstances in supply and demand. Supply chains for specific products will be slightly different but in general they

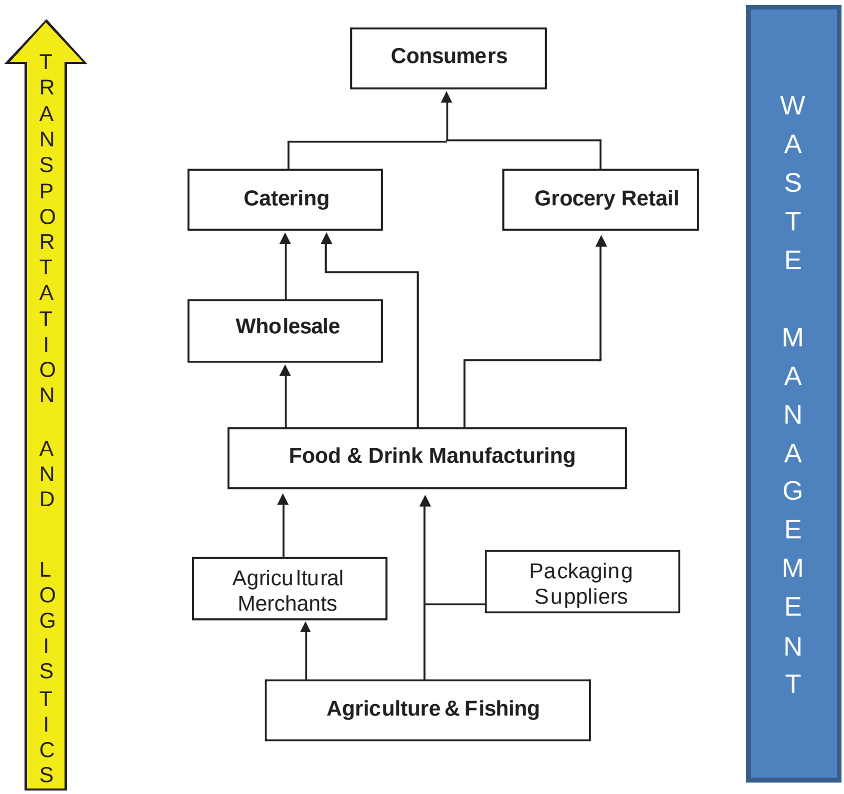

Figure 18.3 The food supply chain.

tend to have six major players: consumers, retailers, caterers, wholesalers, manufacturers and primary producers, including farming and fishing (see Figure 18.3). Other participants in the industry include packaging suppliers, agricultural merchants, logistics service providers and waste managers.

Waste can arise at any echelon in the supply chain, including the final consumer, and the further downstream in the chain an item is wasted the greater the loss in terms of value and natural resources. However, efforts to tackle waste often lack traction because the total cost of waste is frequently undervalued as costs, such as energy and water use, are 'hidden' in other stages of the chain (Binyon, 2007). Furthermore, actions in one stage of the chain can affect waste in other stages. This complexity means that the waste problem requires holistic solutions.

The role of the key players in the food and drink supply chain and the impact they can have on waste are briefly discussed below with respect to consumers, retailing, wholesaling, manufacturing, catering, logistics and transportation, primary production and packaging.

18.2.1 Consumers

Consumers set the pace of demand in the food supply system. Retailers and manufacturers continuously look for new trends in customer demands, such as increasing emphasis on healthy eating or concern for ethical issues, and then introduce new products or adapt existing products to satisfy them. In this way consumers play a key role in shaping the structure of food supply chains and the individual strategies that food companies follow.

World statistics on food waste are non-existent, so it is difficult to compare different countries to identify good practices and opportunities for improvement. There is anecdotal evidence that in developing countries most waste is generated downstream at the consumer end of the chain due to lack of appropriate refrigeration equipment, while in developed countries waste tends to be concentrated at the primary production stage because of higher quality standards (Dobbs, et al., 2011; Parfitt, et al., 2011).

Traditionally, it has been estimated that in UK households one third of all purchased food is wasted (mainly fruit, vegetables and bakery) which represents around £600 of the average family annual grocery bill. According to WRAP (2009), in the UK one quarter of all food purchased (by weight) per year is wasted. For 2010, WRAP (2011) estimates a total of 7.2 Mt of household food waste (out of 38 Mt of food and drink brought into homes). Of that amount, 66% was avoidable, while the rest can be split equally between possibly avoidable and unavoidable. This is in line with Ventour's (2008) results which state that 61% of total waste could be avoided by better handling. The top five avoidable waste products by weight are fresh fruit and vegetables, bakery, fresh meat and fish, dairy products and rice and pasta (Caswell, 2008).

Not all food waste is avoidable, but estimates indicate that about 5.3 Mt are avoidable and (in addition to 1.5 Mt unavoidable), another 1.5 Mt are classified as potentially avoidable (meaning that some people would eat the food, but not everybody, WRAP, 2011). In addition to food being wasted by consumers, it is estimated that about 3.6 Mt of packaging waste associated with food products is generated by UK households per year (WRAP, 2011). This brings the total volume of waste generated by UK households to 11.9 Mt.

In households the reasons for wasting food are mainly due to:

- Misinterpretation of product labels (leads to unnecessary discarding), or incorrect storage that reduces the product's shelf-life.
- Inappropriately large portion sizes. In recent decades, abundant food availability has brought about some complacency in the purchase and preparation of oversized meals at home. In some countries this culture is particularly widespread and would require a great awareness campaign to change it. It has been demonstrated that refills and self-dispensing systems (mainly in countries with that type of buying culture, as happens in the USA

and Asia Pacific region) encourage consumers to buy smaller portions and potentially help to reduce food waste (Cox et al., 2010).
- Cultural habits in which edible parts are not eaten (apple skins, bread crusts, etc.). Years ago in rural areas particularly, certain leftovers were still used (e.g. bread from previous days to prepare some soups, etc.), but nowadays this tradition is being lost. As an example, originally the traditional Spanish dish 'paella' was a way to make use of leftovers, to which rice was added.

18.2.2 Retailing

The scale and structure of the food retailing sector varies significantly from country to country. In many developed countries the sector appears to be highly consolidated and dominated by major multiples such as Wal-Mart, Carrefour, Ahold, Tesco and Metro. These multinational firms tend to be relatively efficient and the proportion of waste they generate relatively small. In the UK, which has a very concentrated retail sector, it is estimated that about 0.4 Mt of waste are generated in retail, accounting for only 2.5% of total food waste (WRAP, 2011).

Kantor et al. (1997) estimate that 2% of fresh fruit and vegetables are wasted in the US retail sector. Gustavsson and Stage (2011) undertook a study of nine Swedish retail stores analysing whether packaging affects the waste of fruit and vegetables. They conclude that most wastage comes from broccoli (6.3%), strawberries (4.8%), cauliflower (4.7%) and celery (4.7%) (i.e. products that are sensitive to rough handling); the lowest wastage is from onions (0.4%) and cabbage (0.7%). Their conclusions did not support the belief that packaging reduces wastage in these products. However, they did discover that small retail stores produced relatively more wastage in general.

Waste in the retail sector tends to be caused by food items, especially chilled, being high in complexity and in a compound form (an example being sandwiches, which contain varied, processed ingredients that are not able to be reversed into raw ingredients). There is evidence of managing waste by using reusable green packaging trays and cutting down on cardboard as well as using charities to distribute surplus food to avoid landfill.

At the retailing level, the main source of waste generation is the sale of products with a short shelf-life. Unsold products arrive at the shelves on their expiry date or are aesthetically unappealing to the customer. These circumstances trigger marketing promotions that pass the problem of later waste generation to householders (e.g., 'buy one, get one free' promotions). Another important source of waste at this level is defective packaging that makes the withdrawal of perfectly edible products necessary.

Table 18.2 summarizes the characteristics of the main retail formats and comments on the implications that each store format can have on waste.

Table 18.2 Retail formats and causes of waste

Convenience	Small stores with sales area up to 3,000 sq ft (280 m^2). Usually located in busy city centres, residential areas, small towns, petrol stations forecourts. In this format waste as a percentage of sales is likely to be higher than in other formats due to the higher proportion of short shelf-life products such as sandwiches and chilled foods.
Supermarket and Superstore	Sales area between 3,000 and 60,000 sq ft (280 - 5,500 m^2). Larger than convenience stores and offering a wider selection of products. Usually located close to residential areas to be convenient for consumers. Ample shopping hours and systematised practices could result in lower volumes of food waste compared to convenience stores.
Hypermarket	Sales area above 60,000 sq ft (5,500 m^2). Usually located in suburban or out-of-town locations that are accessible by automobile. Carries a very wide range of food and non-food products. Ample shopping hours and systematised practices could result in lower levels of food waste as a proportion of sales. However, the wide range and the presence of many low turnover products could generate some waste.

18.2.3 Wholesale

Wholesalers connect the supply activities (agriculture and manufacturing) with the market activities (retail and catering) forming an essential link in the supply chain. The main services provided at this stage are warehousing, transportation, product consolidation, inventory management and retail/catering advisory services.

There are two main types of food and grocery wholesalers (IGD, 2007):

- Cash and carry: where the customer buys and collects the goods from the wholesaler who generally offers a limited number of consumable products such as cigarettes, general groceries, confectionery and soft drinks.
- Delivery wholesalers: offer a delivery service to the customer's location for a fee. This type of wholesaler offers a broad range of consumable products including frozen and chilled, household, health and beauty, snack meals, fast food and leisure products.

Like retail operations, wholesalers tend to have relatively low levels of waste as products are not transformed and generally they are not kept for long periods of time. The dominant cause of waste is related to storage and inventory management (Terry et al., 2011).

However, some practices contributing to waste should be mentioned here, such as customer-supplier agreements which allow, under certain circumstances, the return of unsold products.

18.2.4 Manufacturing

The food manufacturing industry comprises a variety of sectors and processes such as meat and poultry processing, brewing, dairy, confectionery and frozen ready meals, to name but a few. The majority of food manufacture is performed by very large organizations, which operate across a range of markets (Fenn, 2009). In the UK, it has been estimated that the largest 3.8% of food manufacturers produced 76.5% of all the output in 2004 (Defra, 2007c). These larger firms, which have a stronger bargaining position compared with retailers, tend to have larger margins than smaller firms.

Food manufacturing inevitably causes some waste. Statistics from WRAP indicate that, in the UK, waste generated by the food manufacturing industry amounts to 3.2 Mt per year, which represents about 20% of total food waste (WRAP, 2011). As in the case of household waste, some of this waste might be unavoidable, such as vegetable skins and animal carcasses, or from food trimmings and processing, nevertheless there is still considerable scope for improvement in the food manufacturing sector.

Waste generated in food manufacturing processes can vary significantly depending on the type of operation being carried out. Figure 18.4 categorizes food manufacture operations and presents some examples of the types of waste produced.

18.2.5 Catering

In the food service sector, again issues such as portion sizes (large menus), the difficulty of forecasting the number of clients and their requirements and preferences, or the lack of acceptance of taking leftovers home that happens in some countries, make these industries a significant source of waste.

A special situation is evident in the fast food sector. Aarnio and Hämäläinen (2008) studied this case considering 87 McDonalds Oy restaurants in Finland. They claim that although from the selling point of view they should be classified as restaurants, the production techniques resemble the food industry (reduced number of options, small number of raw materials, assembly processes, packaged in standardized single use packages). They realized that in this sector a *bigger* problem than the actual food waste is that of packaging waste. Only 29% of all recyclable packaging is recovered from those restaurants. The research concludes that, in order to increase the recovery rate, it is necessary to devise new waste management practices in collaboration with public authorities, by developing new ways to increase customers' awareness, and by using more consistent waste management infrastructures.

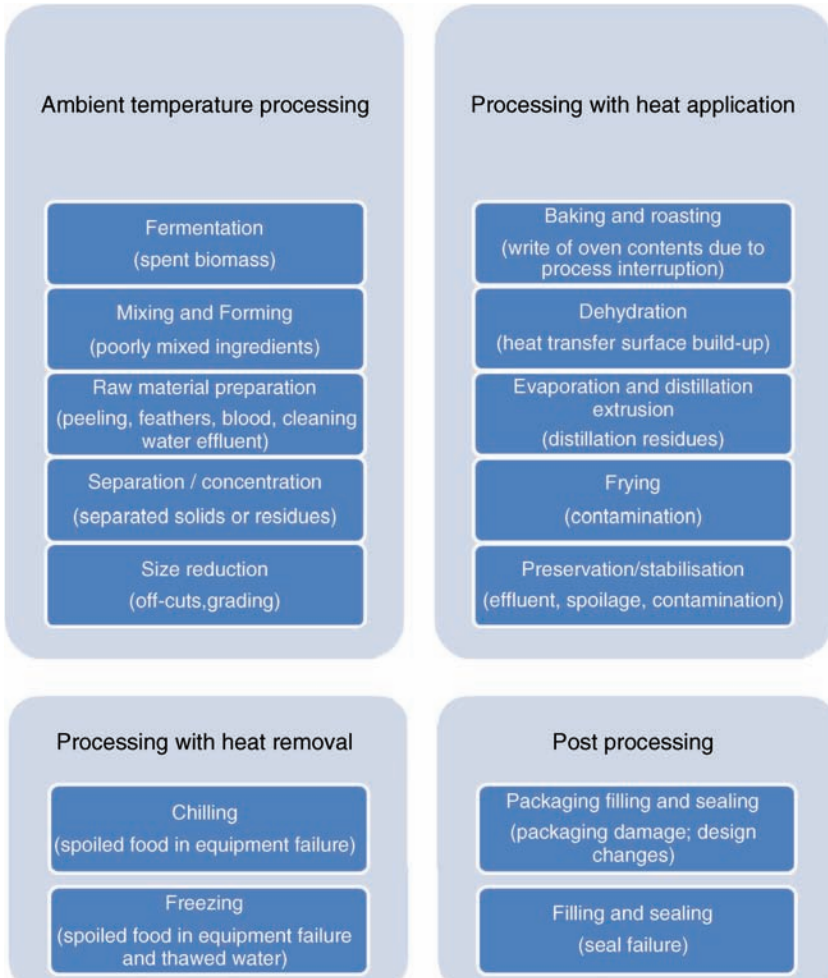

Figure 18.4 Food processing unit operations and associated waste (examples provided in brackets; adapted from Fellows, 2000).

18.2.6 Logistics and transportation

The competitiveness in the market, the diversity of products on offer and the complexity of retail operations, demand a logistics system that has to be both efficient and adaptable. This is arguably the reason why logistics has become an important differentiator in the marketplace and retailers have used it as the mechanism to control, organize and manage end-to-end supply chains (Bourlakis and Weightman, 2004).

Given the enormous number of products managed by large retailers there is a latent necessity towards the use of distribution centres. Retailers channel the majority of their products through distribution centres before reaching the stores; some tend to use their own transportation fleets to replenish the stores, while others rely on third party logistics providers. Having greater control over secondary distribution means retailers might be able to manage their transportation and replenishment systems with greater efficiency. In this sense, however, they are heavily dependent on IT systems and, very often, logistics providers.

Waste at this stage is influenced by a variety of factors and management practices; the segments at highest risk are chilled and frozen food, which depend on a constant temperature to avoid food spoilage. Other challenges include damage in transit and errors emerging from forecasting discrepancies which are not passed onto retailers (Fellows, 2000; Food and Drink Federation, 2007).

Another potential source of waste at the distribution stage relates to the way inventories are managed, as the higher the inventory level, the greater the likelihood that the product will be damaged or exceed its best-before date. Hence by improving inventory management, waste levels could be reduced. The implementation of initiatives such as 'composite distribution' and 'common stock rooms' has brought substantial gains in terms of reduction of inventory and overall efficiency of the whole logistical system. Composite distribution refers to the 'distribution of mixed temperature items through the same distribution centre and on the same vehicle' (Smith and Sparks, 2004). Common stock rooms are widely used in mixed retail businesses; the basic idea is that a group of stores share the stock from a common room strategically located in one of them according to demand requirements (Fernie and Sparks, 2004).

18.2.7 Primary producers

Primary production in the food and drinks industry comprises a wide variety of activities, the two main categories being farming and fishing.

On the farm, there are three main reasons for wastage: severe weather (droughts, freezes, hurricanes, etc.), quality standards (when some small but edible produce remains in the field) or technical factors (produced by equipment and mechanized limitations). However, these leftovers are usually used as fertilizer or animal feed.

18.2.8 Packaging

Packaging presents a trade-off in terms of waste because although all packaging eventually becomes waste, it also protects products from damage and helps to extend the shelf-life of many products. For this reason, packaging has become a necessity for modern food production.

As discussed previously, estimates indicate that UK households alone generate about 3.6 Mt of packaging waste associated with food products (WRAP, 2011). In addition to this, 1.1 Mt of packaging waste are generated in retailing and 0.4 Mt in manufacturing (WRAP, 2011). These figures amount to 5.1 Mt of food-related packaging across the supply chain.

The majority of waste created from packaging materials comprises glass, cardboard and plastics. Most of these are able to be reused and recycled so disposal within landfill is not an effective use of these resources.

18.3 What happens to food waste?

Once food is discarded, there is an environmental problem regarding what to do with it. The waste management hierarchy (Defra, 2007b) gives industry a structure for the management options of waste, as follows:

- waste prevention;
- re-use;
- recycle;
- energy recovery;
- safe disposal.

Figure 18.5 shows the relationship between the steps in terms of priority and ideal quantities, that is, more waste prevention than waste re-use. Waste prevention aims to avoid producing waste in the first place and should be carried out ideally before any of the other solutions in the hierarchy. The main aim is to cut down on waste going to landfill and to obtain the full potential from materials and foodstuffs rather than produce waste for the sake of it (Defra, 2007a).

For the food industry, general waste minimization activities include improving operational practices, increasing control of existing waste operations and

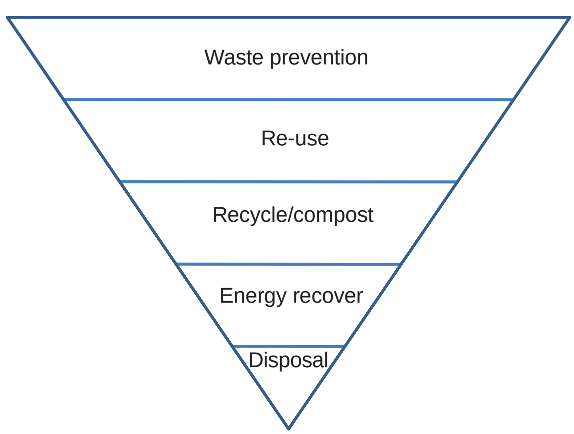

Figure 18.5 The waste hierarchy (Defra 2007b. © Crown Copyright 2007).

introducing innovative process technology (C-Tech Innovation, 2004). Implementing this step presents the challenge of investing money in operations. However, this investment will be recouped as other disposal methods, such as landfill and incineration, become more costly and deemed more environmentally damaging.

Re-use of materials where possible is the next step. However in the food industry there are barriers to applying this approach. The limiting factor is generally hygiene requirements; for example, any re-use of packaging would require a high standard of cleaning before it can be re-used which is often not cost effective (C-Tech Innovation Ltd., 2004).

In terms of recycling and composting, the food production industry has a wealth of options available that can often lead to further income streams because the by-products can either be resold to food producers or re-used by the manufacturer in other operational procedures (Fellows, 2000; Kim et al., 2011):

- Composting. After controlled aerobic degradation (major technologies are windrow composting, aerated static piles, tunnel composting, in-vessel composting, see Diaz et al., 2007), the product can be applied for soil improvement or plant feeding. Composting can be performed either at home (low tech gardening composting), decentralized, or centralized as a large-scale solution.
- Anaerobic digestion. Under such conditions, biogas (mainly methane and CO_2) is produced, burnt to generate electricity and the extra heat from the process used to heat the digesters. Digestate is used as a land nutrient, although given the large volume of wet and non-disinfected sludge generated, dewatering is required for quality soil amendment. The different reactors can be classified (Levis et al., 2010) according to solid contents of the feed, number of stages, operating temperature (mesophilic or thermophilic), and the method of introducing the feed into the reactor (continuously or in batches).
- Co-digestion with sewage sludge. Food waste is mixed with sewage sludge and treated anaerobically, to get biogas.

Other options for waste disposal that would lie at the bottom of the hierarchy include:

- Dryer incineration. After drying and the volume reduction, waste is mixed with municipal solid wastes and transported to incineration, in order to heat some neighbourhoods. Incineration is generally perceived by the public to be environmentally unfriendly and a health damaging method of disposing of waste which is surrounded by high levels of legislation and regulation. In other countries where technology for converting incinerated waste into energy has progressed substantially (where conversion efficiency is approximately 75%) (C-Tech Innovation, 2004), it is deemed to be a tolerable

diversion route for waste from landfill. It should be noted, however, that ultimately the resulting ash is often landfilled.

- Discharge to sewage pipe. Made after grinding by a disposer within a sink; this is prohibited in many countries.
- The rendering of animal by-products from the meat production chain is estimated to be a cost-effective means of disposal at least in the medium term due to the legislation mentioned previously in this report. It is estimated that 1.75 Mt of this waste is to be dealt with annually which produces 0.25 Mt of fat and 0.4 Mt of protein meal through rendering (C-Tech Innovation Ltd, 2004). Animal feeding is another alternative; after sorting and shredding some wastes, the resulting product can be supplied to animals, whether dry (22% moisture) or wet (69% moisture).
- Landfilling. Also banned in many countries (because of the risk of groundwater contamination from the leachate, GHG emissions, massive truck contamination, odours, smog, loss of fertile land, etc.), landfill gas can be used to be converted to electricity, although recovery of methane is costly and only 50% efficient as compared with anaerobic digestion, with a low conversion into electricity of only 35%. Increasing cost of collection, as well as taxation (in UK £40/tonne in 2009; €24 in Spain, according to Mena et al., 2011) helps to promote looking for alternative destinations.

Landfill is the UK's prevalent waste disposal route and handles 50% of industrial waste. There have recently been several drivers for change in the implementation of the waste hierarchy and to reduce this figure. These include categorizing waste (into hazardous, non-hazardous or inert), reduction of active landfill sites and a ban on tyres going into landfill. Also imposed have been the banning of liquids, the requirement of pre-treatment for non-hazardous waste (both from October 2007) and the planned closure of some landfills by 2009 (Defra, 2007b).

In the USA (Levis et al., 2010) over 97% of food waste is estimated to be disposed of in landfills (28.07 Mt out of 28.80). The goal alternative is to divert the waste, for instance to be treated biologically. Levis et al. (2010) identified 300 facilities in the USA accepting food waste for composting (only a quarter accepting residential wastes), most of them with a small capacity (less than 100 t/week), and then selling the compost in bulk. However, only two anaerobic facilities were studied by them in all North America (one in Canada and one on the US west coast). In the 1990s in Europe only 0.7% of total organic municipal waste was treated anaerobically, and in the range 6–27% was composted (De Baere, 2000). Refsgaard and Magnussen (2009) report that in Norway, of the 28% of food wasted, 30% is landfilled, 30% composted and 30% incinerated, being 35% the estimation of the waste treated biologically in all Europe.

In those countries where landfilling is restricted, animal feeding and composting are usually the most used alternatives. For instance, in Korea (Kim et al., 2011), 45% of food waste is used for each of those two purposes.

The authors also conclude that the cost benefit ratio of wet feeding is the highest of all alternatives, while landfilling is the lowest.

However, in spite of the development in many countries of large scale compositing centres, many of them have discontinued operation, mainly because of the poor quality of the contaminated compost produced, and the high cost of the compost compared with the generation cost (Sharholy et al., 2007).

Many studies have investigated the environmental impact of these alternatives. As an example, Bernstad and Cour Jansen (2011) studied different alternatives to be applied in Sweden, a country whose national environmental objectives stated that 35% of all organic household waste had to be biologically treated in 2010. After considering incineration, decentralized composting in residential areas and anaerobic digestion, either with upgraded biofuel to be used as petrol in light vehicles, or only used for electricity generation, they found, after performing a life-cycle assessment (LCA), two contradictory results: when compared with incineration, both biological treatments avoid GHG emissions (mainly when upgrading biogas), but at the same time they contribute more to nutrient enrichment and acidification.

Of course, these LCA studies are very dependent on the country. In Australia, with large distances for collection, Lundie and Peters (2005) compared a household in-sink processor, landfilling and composting (at home and centralized with weekly collection). The results showed that composting at home resulted in the least impact in all categories while the centralized alternative has a poor performance due to the energy intense collection phase. Landfilling offers problems regarding climate change and eutrophication, while the sink alternative requires high water consumption, which represents a serious problem in the country.

18.4 The causes of food waste

Waste is an undesirable effect resulting from the complex interaction of management practices, product characteristics, consumer trends and environmental factors. Incidents leading to food waste are seldom the result of a single cause but rather from a combination of factors occurring simultaneously. For instance, poor information sharing, combined with a short shelf-life product and a spell of cold weather could lead to substantial amounts of waste.

From farm to customer, a typical food product is handled an average of 33 times (Kantor et al., 2997). In these long supply chains there are many opportunities to generate waste. As discussed in the previous sub-section, at every stage of the food supply chain waste can result for a variety of reasons. Due to this complexity it is difficult to attribute specific amounts of waste to each cause. However, it is possible to identify those causes that appear to be having the most influence on waste. Table 18.3 presents a short description of the leading causes of waste in the food and drinks industry.

Table 18.3 Main causes of wastage

Cause	Description
Packaging	Packaging plays a dual role in terms of waste; on the one hand it protects the product from damage and can help to extend its shelf-life, having a positive effect on waste. On the other, the amount of packaging on a product has a direct impact on household waste and to some degree on waste generated at other stages in the chain.
Product damage	Poor practices in product storage and handling, coupled with packaging and palletising practices, can result in damaged products which are discounted or discarded.
Product recalls	Product recalls are relatively rare events. However, when they occur they are likely to generate large amounts of waste, particularly for products with long shelf-lives since they are likely to have more stock in the pipeline.
Forecasting	Estimating the demand for a product is a complex and inherently inaccurate activity which can be affected by many factors such as weather, seasonality, marketing campaigns, product launches, promotions and special occasions such as Christmas and Easter. Forecasting error has a direct impact on waste, particularly for products with short shelf-lives. Hence the forecasting approaches and methods used by both retailers and manufacturers are key to reducing waste.
Information sharing	Accurate and timely information is essential for good planning and forecasting. When information is scarce there tend to be large variations between forecast and orders which often result in waste. Furthermore variations caused by poor information sharing can amplify across the supply chain (i.e. bullwhip effect).
Promotions	Demand during promotional periods is notoriously difficult to forecast and the increased forecasting error is likely to lead to increased waste. Furthermore, promotions can also increase household waste as customers might buy unusually large quantities of product.
Shelf-life policies	Most mainstream retailers have policies of only accepting product with a high proportion of shelf-life remaining (usually over 70%). This is particularly problematic for own label producers who are unable to sell the product through other channels, such as discount retailers.
Inventory management	Inventory management policies, particularly around safety stock levels are likely to have an impact on waste.
Stacking and shelving	Stocking and shelving can have an impact on product damage but also on product selection by customers who will prefer those products with the longest shelf-life available.
Penalties and availability targets	Penalties are a mechanism used to ensure that deliveries are made on time and in full. However, they can encourage manufacturers to over-produce to cover themselves against the risk of penalties or de-listings.

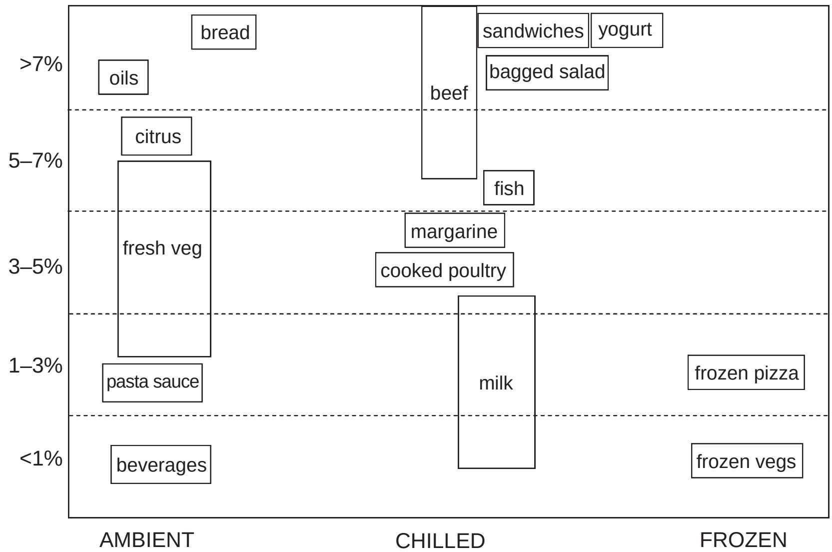

Figure 18.6 Waste ranges for different products (Mena et al., 2011. Reproduced with permission from Elsevier).

Mena et al. (2011) present one of the few studies of waste in the interfaces of the food supply chain, looking for the root causes of the problem. They studied different products, analyzing the percentage of waste in the supply chain in Spain and the UK. Figure 18.6 shows the waste ranges for the most problematic products. Only six products got more than 7% of rejection: bread, sandwiches, salads, yogurt (all with a short shelf-life), beef (with a volatile demand), and oils (in this case mainly due to fragile packaging). Frozen products represent the lowest wastage ratio given their long life, although maintaining the cold chain can cause problems as well.

These authors identified three main groups for classifying the root causes of food waste:

a) Natural factors

These are factors that influence waste, but that are associated with the nature of the products or process. Issues such as short shelf-life of fresh products, seasonality of supply and demand, and weather fluctuations are among these factors.

b) Product factors

These refer to trends in the industry, such as increasing demand for fresh products (more and more coming from distant countries after weeks of sailing, instead of consuming local seasonal produce) and rejection of preservatives, which are also affecting waste generation.

c) Management factors

The previous two groups are largely outside the scope of a firm's decision making, but many other causes can be corrected by companies. These are factors affecting waste on which management practices have a direct impact. We believe these are the root causes that are worth exploring in detail, since it is by changing these issues that organizations will be able to reduce waste. Each of these causes is discussed in more detail below (Mena et al., 2011):

- **Waste management responsibilities:** While some companies have very clear roles and responsibilities for managing waste, others do not have a specific role within the company which focuses on waste. This usually means that waste is not measured and managed systematically and this situation is likely to lead to increased waste.
- **Information sharing:** Accurate and timely information is essential for good planning and forecasting. When information is limited, variations between forecast and orders can increase and this could lead to waste. Furthermore, variations caused by poor information sharing can amplify across the supply chain. This amplification is a commonly known phenomenon known as the bullwhip effect (Lee et al., 1997). While some companies are effective at sharing information with their supply chain partners, others are not. For instance, it was found that some retailers would charge for point of sale (POS) data, while others would give it away free. Poor practices in terms of information sharing can not only create waste but undermine confidence in the information provided.
- **Promotions Management:** Promotions are an important strategy for driving footfall and sales in retail stores. However, they can create more unpredictable demand patterns, not only for the products being promoted but also for other products, due to cannibalization. Higher unpredictability can in turn lead to over-production and waste, particularly for products with a short shelf-life. The research revealed that different promotion mechanics and practices can influence how much variability is created and that having clear processes for managing promotions and following them is critical. Promotions can also increase household waste as customers might buy unusually large quantities of product. This 'forward buying' can lead to waste, particularly when product shelf-life is short.
- **Forecasting:** Poor forecasting was one of the most common issues identified during the interviews as a cause of waste. However, estimating the demand for a product is a complex and inherently inaccurate task which can be affected by many factors, such as weather, seasonality, marketing campaigns, product launches, promotions and special occasions such as, for example Christmas and Easter.
- **Performance measurement:** The emphasis in the industry appears to be on cost, efficiency and availability. Although waste has an impact on all of

these factors, it is not usually a key performance measure and it can be sacrificed at the expense of other performance indicators. For instance, most mainstream retailers have policies of only accepting product with a high proportion of shelf-life remaining (usually over 70%). This is particularly problematic for own label producers who are unable to sell the product through other channels, such as discount retailers.

- **Packaging:** Packaging can affect waste in two different ways. On the one hand, it has a positive impact on waste because it protects the products from damage and can help to extend the shelf-life of some products. On the other hand, packaging will at some point go to waste, either in the supply chain or at the point of consumption, so excessive packaging is to be avoided. From a waste point of view, the decisions about how much and what kind of packaging to use are critical. Another related issue involves changes to packaging and labelling for marketing reasons which can cause waste, because packaging is usually bought in large quantities, well in advance of production.
- **Cold chain management:** Cold chains can help maintain product quality and avoid spoilage. Cold chain abuse, caused by equipment failure or poor processes, will inevitably cause waste. The research revealed that failure in maintaining the cold chain can have a severe impact on waste, but these situations are relatively rare.
- **Training:** In some cases people do not follow procedures for stacking, shelving and stock rotation, all of which can lead to waste. This issue appears to be more prevalent during the Christmas period when temporary labour is hired to cope with high demand.
- **Quality management:** Quality issues can lead to rejections and even product recalls. Rejects in particular appear to be prevalent in the fruit and vegetable sector where product quality can be variable, particularly at the beginning and end of seasons. While quality issues can lead to waste, the loss of product quality appears to be more important to the companies than the waste created. Product recalls are relatively rare events. However, when they occur they are likely to generate large amounts of waste, particularly for products with a long shelf-life since there is likely to be more stock in the pipeline.

Table 18.4 shows a summary of the main waste causes and their main impacts in the different links of the food supply chain.

18.5 How to tackle food waste

Having identified the problems and the social, economic and environmental repercussions that food waste generates, the logical path to follow is to evaluate solutions to stop this situation with different kinds of initiatives, mostly trying to reduce waste at its source (according to the Food Waste Recovery Hierarchy).

Table 18.4 Summary of causes and main links of the food supply chain affected

Cause	Primary Producer	Manufacturing	Catering	Logistics	Retail	Household
Weather	•				•	
Technical malfunctioning	•	•				
Business agreements	•	•				
Product quality req.	•	•			•	
Aesthetic	•	•	•		•	
Inventory & management policies		•	•	•	•	
Planning & forecasting		•	•		•	•
Labelling & knowledge			•		•	•
Portion sizes			•		•	•
Culture habits			•			•
Promotions		•			•	
Cold chain				•	•	•
Packaging		•		•	•	•

Approaches being carried out to reduce waste can be classified as follows:

- *Information to stakeholders and consumers*
  A first step for companies and citizens to take corrective action is to make them aware of the alarming statistics and their impact. Several agencies have conducted studies and published reports that the media have at times made public. However, a difficulty in the preparation of these reports is the lack of standardization of methodologies to estimate the waste generated (Dobbs et al., 2011; WRAP, 2010). Sometimes there is no consensus on the concepts and, depending on the countries and their food habits, some waste may be considered as edible or not.

  Despite the importance of measuring the real waste generated, there is little authoritative data on food waste and composition. Prior studies are not easily comparable, given the different methodology and waste classification used. Among the variety of methods used we could find composition analyses, self-measurement methods (kitchen diaries, questionnaire surveys) and statistical estimations from databases (Lebersorger and Schneider, 2011). The first of these is the most objective and accurate but costly, as samples should be collected daily in order to avoid items degradation (Langley et al., 2010). In addition, there are no inter national methodological standards (whether doing it with or without prior sieving, sampling from containers or vehicles, etc.). Regarding self-measurement methods, they are subjective and require significant effort from participants. They require close interaction with small groups of

around 50 participants (Sharp et al., 2010), who are provided with weighing scales (to be used on a weekly basis) and monitoring forms. Other alternatives used (for instance in the Love Food Champions campaign) included a kitchen caddy to be filled with discarded food each day to measure waste generation. Another important issue is what to do with packaging: given the small weight of food packaging (8% when compared with the mass of avoidable food waste). Lebersorger and Schneider (2011) recommend that packaged food waste should not be separated from its packaging in order to avoid a loss of information.

Several studies have identified a lack of knowledge with respect to the exact meaning of the labels ‘best before’, ‘sell by’ or ‘use by’, of which almost half of the population seems to ignore the exact meaning, as an important cause of household waste (WRAP, 2010). Since ‘best before’ is only related to quality but no safety issues, the customer might discard perfectly edible products if following the indication of the label. However, the aesthetic aspects of the product (which in some cases lead to the ‘best before’ date) can be directly judged by the consumer regardless of the label. Also, information on the most appropriate ways of storage (fridge, temperature, type of wrapping, etc.) can significantly extend the edible life of products, even beyond their expiry dates.

The consumer has an important role to play in food waste reduction. Some suggestions that are given to them include (Caswell, 2008): plan meals for the week in advance; check the use of ‘use by’ dates on perishable goods; freeze all food you can according to producer instructions; avoid buying excess fresh food; choose frozen or canned alternatives. Governments have started different campaigns in order to make the general public aware of all of these.

- *Regulatory measures*

Some governments have started to take action to achieve certain food waste prevention targets. In Europe, there are EU Directives that set medium term goals, to which member states must adhere. Here we could include actions such as European Commission Regulation No. 1221/2008 that reduces the aesthetic requirements for fruit and vegetables, preventing discarding and making available for consumers perfectly edible products; or the obligation of segregating biodegradable waste or food waste for industries or households. This may also have a side effect of making clear the large amount of waste generated.

Tax policies for disposing of organic waste can also contribute to reducing the figures. Experience shows that this measure reduced by between 25–45% household solid waste in the USA (Kantor et al., 1997). Looking at Canada, the Maritime Provinces (with high tipping fees for garbage) were recycling more than 50% of their food waste, while in other Canadian provinces (such as Quebec) recycling is only at 7% (Adhikari et al., 2009).

- *Awareness campaigns*
  Different organizations (often governmental ones) have established campaigns that aim to raise people's awareness on this issue. Campaigns such as 'Calling time on Waste' of the Irish government to reduce waste in bar trade, or 'Love Food Hate Waste', sponsored by WRAP, through their reports explain the benefits of food waste reduction and how to achieve it. In many cases, it is intended to promote consumer awareness on purchase planning and avoid the 'buying too much' phenomenon.
  At the private level, one could mention the British retailer Morrisons (2012) which launched the campaign 'Great Taste, Less Waste' for counselling its clients on packaging, storage advice and labelling, so that products bought by them are used more efficiently. The Swedish caterer Eurest (2010) started a campaign to quantify food waste, by weighing the waste and informing its customers and staff. The objectives were to measure waste and evaluate how it could be prevented.
- *Food diversion*
  Another way to approach the reduction of edible potential waste is to lengthen the shelf-life of food, taking products out of the chain and transferring them to other, less demanding markets. Table 18.5 shows the retailers' waste hierarchy for product disposal.
  There are several non-governmental organizations (NGOs) that collect food which is going to be discarded by retailers or in school canteens, and distribute it to different groups of people in need. Food Banks are organizations already established in many countries. In other countries there are local charities that do the same work (such as FareShare in UK, Good Samaritan in Italy, etc.). With those food donations they can serve some 'expensive' items (desserts, meats) that needy people could not afford, complementing a healthier diet.
  Charities obtain their food donations mainly from four streams (Kantor et al., 1997): field gleaning (collection of not economically profitable crops from farmers' fields), salvage (collection of perishable products from

Table 18.5 Retailer's waste hierarchy for product disposal (adapted from Alexander and Smaje, 2008)

Rank	Option
1	Sell to customer at full price
2	Sell to customer at reduced price
3	Use in staff restaurant
4	Sell to staff
5	Donate to charities for human consumption
6	Donate to farms, zoos, animal sanctuaries, etc.
7	Use for producing energy (e.g. biogas)
8	Dispose to landfill

retailers), rescue (collection from restaurants and caterers), and collection of non-perishable longer shelf-life products. Of course all these collections have extra costs associated with transporting, storage and packaging of donated food, as well as training of volunteers. However, many companies are reluctant to divert food waste (often called 'surplus' to avoid the negative meaning of the word 'waste') to charities due to the possibility of inadvertently causing poisoning and the legal implications this might bring. To avoid reluctance of companies to participate in these campaigns, The Bill Emerson Good Samaritan Food Donation Act was passed in 1996 limiting the liability of food donors to intentional misconduct. Also in the USA some tax benefits can be obtained by food retailers when donating their products.

Alexander and Smaje (2008) have observed some conflicting aims between participating agents, as retailers try to maximize profit which means delaying donations, while charities need early donations to maximize utility for recipients. According to their study, around 40% of food donated by retailers is returned uneaten to the waste stream, which does still mean that an important 60% of donated food avoids being disposed of as waste.

Other diversion alternatives are using this food to feed animals, or diverting those wastes from landfill sites to composting or anaerobic digestion systems for the generation of biofuel. In the UK, large retailers are turning their attention to anaerobic digestion as an economically interesting solution to food waste. Sainsbury is currently avoiding every year the landfilling of 56,000 tonnes of expired or damaged products, and generating 30MW of electricity from it (Idle, 2010). They have signed an agreement with a waste contractor to send to its plant all the waste from 40 of its stores. They are definitively supporting this alternative for waste disposal but claim as being a problem the lack of the digesters' capacity.

- *Company initiatives*

  Some companies have found business opportunities around these products before they become waste. Thus, some retailers use near expiry products for sale at the deli counter (for immediate consumption). Some discount stores have specialized in selling at low prices products with very short shelf-lives which have been withdrawn from other retailers. In the UK, in 2009, the Approved Food & Drink Company specialized in selling at discount prices, by using their website, dry food products which were close to their 'best before' date.

  There are other interesting initiatives such as 'Buy One Get One Free Later' developed by Tesco in the UK. Customers can buy perishable goods with a short shelf-life such as yoghurts, vegetable or cheese, obtaining a voucher to collect another one free, one week later. This way the company both avoids having to send to landfill products and increases customers' loyalty. Other initiatives have tried to predict more accurately the sales in cafeterias by requiring reservations for meals, or in school canteens by

changing the time for food (instead of before recess, after playing), or by reducing the size of the meals. Allowing clients to serve themselves with the food they want and then charging for it by weight reduces by 8% the food left on the plate (European Commission, 2010). Note the wastefulness of buffets, where managers cannot let anything run out, and therefore much more food is be cooked than is actually needed.

Another attempt to avoid excessive food purchase has been the commercialization of smaller portions of food, by taking note of the greater number of people who are single or live alone. Note that there is an adverse effect related to packaging: smaller rations can in fact reduce food waste, but increase the necessity for packaging recycling.

In addition, technology can be a good tool with which to fight. For instance, radio frequency identification (RFID) can help to detect actual product quality deterioration in real time, by monitoring temperature profiles for perishable products while stored or during transportation (Wang, 2010). Changes in products' shelf-life can be detected and used to change prices in retailing in order to encourage customers to buy them, with greater accuracy than only having the 'best by' label.

In 2005 in the UK, WRAP launched the Courtauld Commitment to look for new solutions so that less food and primary packaging ends up as household waste. In five years, 0.67 Mt of food waste and 0.52 Mt of packaging have been prevented, according to WRAP's web page. Companies joining this programme carried out many initiatives to reduce the weight and increase recycling rates of their grocery packaging. Also, the target was to reduce the household food waste by 4%. In March 2010, Phase II was announced which will run until the end of 2012.

18.6 Conclusions

Food waste is a serious economic, environmental and social problem and one to which we all contribute. In this chapter we have provided a discussion of the scale and the causes and consequences of waste at each stage of the supply chain. Furthermore we have presented possible solutions to tackle food waste.

The causes of waste include natural factors such as changes in weather conditions, cultural trends (for instance the consumption of fruit and vegetables out of season), and managerial practices such as ineffective planning and forecasting. Many of these causes are difficult to address as organizations in the supply chain have little control over them. For this reason solutions to the food waste problem should include a combination of avoidance strategies, to prevent waste from occurring in the first place, and mitigation strategies, to provide alternative uses for food that would otherwise be wasted. Appropriate

food recovery policies provide savings to companies and farmers, tax benefits, save landfill, lessen waste collection, reduce CO_2 emissions, and of course, reduce hunger.

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19
Sustainable Cold Chain

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19.1 Introduction

The aim of the cold chain it to stop or reduce the rate at which changes occur in food. These changes can be microbiological (i.e. growth of microorganisms), physiological (e.g. ripening, senescence and respiration), biochemical (e.g. browning reactions, lipid oxidation and pigment degradation) and/or physical (such as moisture loss). An efficient and effective cold chain is designed to provide the best conditions for slowing, or preventing, these changes for as long as is practical. Effective refrigeration produces safe food with a long, high quality shelf life.

Refrigeration is important in both maintaining the safety and quality of many foods and enabling food to be supplied to an increasingly urbanized world. In reality, less than 10% of such perishable foodstuffs are in fact currently refrigerated (Coulomb, 2008). It is estimated that post-harvest losses currently account for 30% of total production (Coulomb, 2008). The production of food involves a significant carbon investment that is squandered if the food is then not utilized. Thus there is a balance to be achieved. The International Institute of Refrigeration (2009) estimate that, in theory, if developing countries could acquire the same level of refrigeration as that in industrialized countries, over 200 million tonnes of perishable foods would be preserved, this being roughly 14% of the current consumption in these countries (Table 19.1).

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Table 19.1 Refrigeration requirements and losses due to lack of refrigeration (adapted from International Institute of Refrigeration (IIR), 2009)

	World population	Developed countries	Developing countries
Population in 2009 (billion inhabitants)	6.83	1.23	5.60
Refrigeration storage capacity (m^3/1000 inhabitants)	52	200	19
Number of domestic refrigerators (/1000 inhabitants)	172	627	70
Food losses (all products) (%)	25	10	28
Losses of fruit and vegetables (%)	35	15	40
Loss of perishable food due to lack of refrigeration (%)	20	9	23

To sustainably provide, safe food products of high organoleptic quality, attention must be paid to every aspect of the cold chain from initial chilling or freezing of the raw ingredients, through storage and transport, to retail display and home storage. The cold-chain consists of two distinct types of operation. In processes such as primary and secondary chilling or freezing the aim is to change the average temperature of the food. In others, such as chilled or frozen storage, transport, retail display and storage in the home the prime aim is to maintain the temperature of the food. Removing the required amount of heat from a food is a difficult, time and energy consuming operation, but critical to the operation of the cold-chain. As a food moves along the cold-chain it becomes increasingly difficult to control and maintain its temperature. This is because the temperatures of bulk packs of refrigerated product in large storerooms are far less sensitive to small heat inputs than single consumer packs in open display cases or in a domestic refrigerat/freezer. Failure to understand the needs of each process results in excessive weight loss, higher energy use, reduced shelf life or a deterioration in product quality.

In the future any noticeable increase in ambient temperature resulting from climatic change will have a substantial effect on the current and developing food cold-chain. A rise in temperature will increase the risk of food poisoning and food spoilage unless the cold-chain is extended and improved. It will also impose higher heat loads on all systems in the cold-chain. In systems that have capacity to cope with these higher loads this will just require the refrigeration plants to run for longer periods and use more energy. In many other cases during cooling operations the food will take longer to cool or during temperature maintenance processes the food temperature will not be maintained at current levels. The little data that is available suggests that currently the cold-chain accounts for approximately 1% of CO_2 production in the world. However, this is likely to increase if global temperatures increase significantly. Using the most energy efficient refrigeration technologies it would be possible to substantially extend and improve the cold-chain without any increase in CO_2, and possibly even a decrease.

19.2 Cold-chain management

Refrigeration has been identified as an area where dramatic emission cuts could be made relatively easily, by using and maintaining energy-efficient equipment correctly (International Institute of Refrigeration (IIR, 2003)).

It is clear that maintenance of food refrigeration systems will reduce energy consumption (James *et al.*, 2009). Repairing door seals and door curtains, ensuring that doors can be closed and cleaning condensers produce significant reductions in energy consumption. In large cold storage sites it has been shown that energy can be substantially reduced and installation made more sustainable if door protection is improved, pedestrian doors fitted, liquid pressure amplification pumps fitted, defrosts optimized, suction liquid heat exchangers fitted and other minor issues corrected. Also, it is well known that the insulation efficiency of insulated panels can be reduced by 5 to 12% per year (Estrada-Flores, 2009). Replacing or augmenting old insulation can therefore provide significant energy savings.

Better design of facilities can also reduce energy consumption. Among the suggested improvements (Duiven and Binard, 2002) are: thicker floor, wall and roof insulation; use of in-feed and out-feed conveyors with lock gates instead of doors; selection of the right compressor and refrigerant; appropriate selection of components of the refrigeration process; and application of speed control for compressors to achieve full-load during refrigeration. They also suggest speed control of fans; electronic expansion valves; adequate pipe dimensions and insulation; advanced lighting methods; defrosting using hot gas; computer control systems, monitoring and data processing.

19.2.1 Primary and secondary cooling operations

To be able to calculate the energy efficiency of current primary chilling processes data are required on the measured energy consumption of industrial systems for a known throughput of the raw material being chilled. Swain et al. (2009) located very few publications that contain both measured energy and throughput data. However, five publications were located that provide some relevant data on milk (Milk Development Council, 1995; Legett et al., 1997), potatoes (Devres and Bishop, 1992) and meat (Collett and Gigiel, 1986; Gigiel and Collett, 1989), which are three of the key primary raw materials in terms of a high primary chilling energy requirement.

There are a number of stages in quantifying the potential to save energy in different primary chilling operations. The first stage is a simple technology transfer exercise in which the most energy efficient current industrial process is identified.

As already mentioned with milk and carcass meat, data exist that allow a first attempt at calculating the energy reduction potential of a simple

technology transfer exercise. In the 1980s Gigiel and Collett (1989) measured the energy consumption, cooling rates and weight loss in 14 commercial beef chillers. The average energy consumption in beef chilling was 116 $kJkg^{-1}$ and the total annual UK consumption 113 TJ. It was estimated that if UK plants reduced their consumption to that of the best measured then the country would save 42 TJ of energy and the industry would increase its profits by 26%.

A second stage of the process is to see if a simple technology transfer between sectors would be beneficial. The cooling of a liquid product such as milk is a very different process to that of cooling solids such as potatoes and meat carcasses. However, since both meat carcasses and potatoes are cooled in air based systems it should be possible to make potato cooling as efficient as the best of the measured carcass cooling plants. This would improve the efficiency of potato cooling from 0.313 to 1.725, which would result in a potential annual saving of 154 GWh in the UK.

There is little specific data on the energy use of specific cooling methods. Duiven and Binard (2002) cite figures of 70 to 130 kWh/ton of product for blast freezing in comparison to 60 to 100 kWh/ton of product for plate freezing. Pedersen (1979) calculated the relative costs of five different chilling methods for poultry. When only energy costs were considered, the cost of a counter-current water chilling system was one fifth that of an air chilling method. However, when the costs of the water and wastewater disposal were added, the water chilling cost was over 50 times that of the air system.

The surface temperature of cooked products is very high when they leave baking ovens or deep fat fryers and consequently the difference between the surface and the ambient is very large at that time. To reduce energy usage and costs a number of food manufacturers have traditionally operated a two-stage cooling operation using ambient air followed by refrigerated air (James and James, 2002). However, the use of ambient cooling is not widespread within the food industry and in some cases it is not encouraged. This is due to belief that the slower cooling rate would encourage bacterial growth and that the distribution of ambient air over unwrapped products could increase bacterial contamination. James et al. (2010) have carried out investigations on the ambient cooling of hash browns prior to freezing and ambient cooling of meat and vegetable pies prior to blast chilling. Hash browns emerged from a fryer at 80 °C and had to be frozen to −12 °C before packaging at a process rate 4.5 tonnes/hr. The existing spiral freezer was incapable of extracting the initial heat load and the moisture loss from the hash browns was causing ice to build up the evaporator. An initial 5 minutes of ambient cooling removed 562,500 kJ of heat energy from the 4.5 tonnes of hash browns every hour. It also prevented 60 kg per hour of water freezing on the evaporator. This reduction was achieved with insignificant increase in total freezing time.

Prechilling of Albacore tuna prior to freezing using a refrigerated seawater system (RSW) removed almost one third of the total heat load and improved the quality of the fish (Kolbe et al., 2004). The RSW system operated more energy efficiently than a low temperature blast freezer (Kolbe 1990).

19.2.2 Distribution

For some foods the preferred storage temperature is still a matter for debate and needs further clarification. Heap (2006) used garlic as such an example, which 'may be carried at a preferred temperature between −4 °C and 0 °C, or at ambient temperature with good ventilation'. This has implications to the requirements for the use of refrigeration and energy consumption.

Providing the product is fully cooled prior to loading and the loading is carried out in a refrigerated loading dock, the only heat load of consequence, during distribution, is infiltration through the structure. As already mentioned insulation materials deteriorate during use and transport containers are periodically tested to see if they are within thermal specifications. Currently the only system that is being considered to improve the insulation of containers is vacuum insulated panels (VIP). Some manufacturers (www.panasonic.com/industrial/appliances-hvac-devices/vacuum-insulation/index.aspx) claim that these panels can be 20 times more efficient than insulated foam panels therefore wall thickness can be thinner and load capacity increased. Due to the development of high performance, low cost materials and manufacturing techniques in the past few years VIPs are becoming commercially attractive.

Many advantages are claimed for liquid nitrogen transport systems, including minimal maintenance requirements, uniform cargo temperatures, silent operation, low capital costs, environmental acceptability, rapid temperature reduction and increased shelf life due to the modified atmosphere (Smith, 1986). Overall costs are claimed to be comparable with mechanical systems (Smith, 1986). However, published trials on the distribution of milk have shown that the operating costs using liquid nitrogen, per 100 litre of milk transported, may be 2.2 times that of a mechanically refrigerated transport systems (Nieboer, 1988).

A review of food transport refrigeration (Tassou et al., 2008) concluded that the Coefficient of Performance (COP) of transport refrigeration systems was low, ranging from 0.5 to 1.75 and that up to 40% of diesel consumed during transportation is used by the refrigeration system. However, the conclusions had to be based on theoretical and derived data due to the lack of any experimentally measured data on fuel consumption by refrigeration systems in commercial use.

Only one example has been located where the amount of fuel consumed by the refrigeration systems in different commercial refrigerated vehicles was actually measured (James et al., 2009). The data, transformed into kWh consumed on the day of measurement, are shown in Figure 19.1. Again it

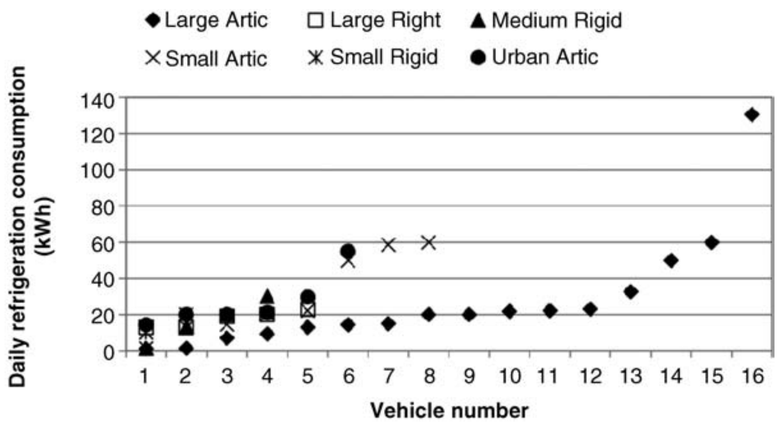

Figure 19.1 Energy consumption of refrigeration systems of transport vehicles.

is clear that there is a wide range of energies used, both between and within categories, and research is required to determine the reasons for the range and transfer of the knowledge obtained to the industry.

The application of photovoltaics (PV) to refrigeration for the distribution of chilled supermarket produce was pioneered in the UK. In 1997 Sainsbury's, a major UK supermarket chain, commissioned the world's first solar powered refrigerated trailer (Tubb, 2001; Bahaj and James, 2002). The trailer operated for four years with the operating power being solely derived from solar energy. In further developments the performance was increased by 27% and the total cost claimed to be competitive with current competition. Operating in the UK it was stated that 'During most of the year there has been an excess of solar energy over daily demand'. It is not clear why commercial systems are not currently available, but it is possible that the high capital cost of current PV systems is limiting adoption. It is anticipated that with time the cost of PV systems should come down and payback times shorten (Bahaj and James, 2002).

19.2.3 Storage

Energy studies on cold stores have shown that energy saving methods are very site specific. In three cold stores a number of methods of reducing energy were investigated (James et al., 2009). Predicted savings in energy if door protection was improved, pedestrian doors fitted, liquid pressure amplification pumps fitted, defrosts optimized, suction liquid heat exchangers fitted and other minor issues corrected would be 23% in cold store 1, 5% in cold store 2 and 39% in cold store 3. It was estimated that if cold store 2 were fitted with an evaporative condenser the savings would increase to 38%.

In recent years, energy conservation requirements have caused an increased interest in the possibility of using more efficient storage temperatures than have been used to date. Many decades ago (Jul, 1982) questioned the wisdom of storage below −20 °C and asked whether there is any real economic advantage in very low temperature preservation. There is a growing realization that storage lives of several foods can be less dependent on temperature than previously thought. Improved packing can also increase storage life and may allow higher storage temperatures to be used. The British Frozen Food Federation (2009) looked at the potential to reduce energy usage and CO_2 emissions by raising the temperature control set point of cold stores and also by raising the associated evaporating temperatures. They reported that 'Savings of over 10% will often be achievable with relatively little capital investment. Even larger savings of over 20% can be achieved in some situations'.

Cold storage refrigeration systems usually operate during the daytime when electrical costs and outdoor temperatures are highest and refrigeration system performance is at its worst. The feasibility of using the thermal mass of the items in storage as a means of decoupling the operation of the refrigeration system from the loads that it serves has been demonstrated by Altwies and Reindl (1999). In this case, refrigeration equipment operates during low utility cost hours (off-peak) to pre-cool the stored items. Then the refrigeration equipment can remain idle during high utility cost periods (on-peak) with minimal changes in the storage environment and product temperature. In many cases, little or no capital investment is required to implement this type of warehouse operating strategy. Although this strategy may save money it is unlikely to reduce energy consumption and may actually increase it if the product is precooled to a much lower temperature than the overall average required.

19.2.4 Catering

Simply replacing current chilled storage cabinets (CSC) by the best available, in terms of energy consumption, could save 1,000 GWh per year (James et al., 2009). In the USA, Sarhadian (2005) measured the energy consumption of refrigeration systems in a catering establishment before and after a refitting operation (Figure 19.2). Over the period monitored energy reductions ranged from 10 to 53%. In the UK, a study carried out in a small catering operation showed that one upright frozen storage cabinet consumed over 40% of the energy used in refrigeration. Two small cost-effective changes, that is, cleaning the condensing coil and resetting the thermostat, produced energy reductions of 8 and 11% respectively (James et al., 2009).

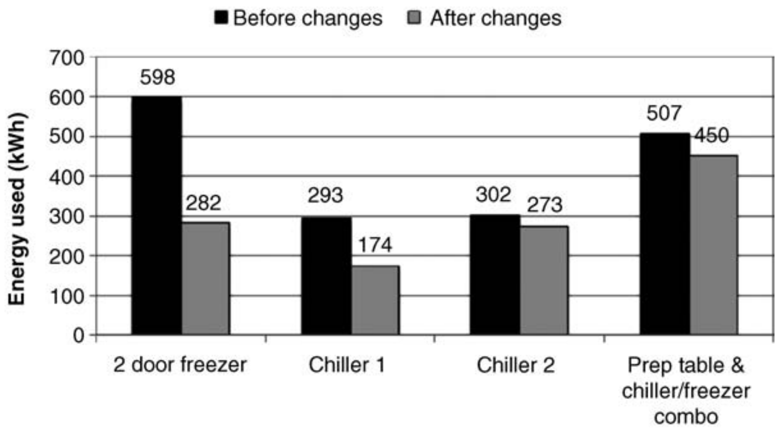

Figure 19.2 Energy used in refrigeration systems in catering establishment pre and post refit (adapted from Sarhadian, 2005).

19.2.5 Retail display

Laboratory trials have revealed large, up to six-fold, differences in the energy consumption of frozen food display cabinets of similar display areas. In chilled retail display, which accounts for a larger share of the market, similar large differences, up to five-fold, were measured. A substantial energy saving can therefore be achieved by simply informing and encouraging retailers to replace energy inefficient cabinets by the best currently available. To quote from an article in the UK's *Guardian* newspaper 'What's the biggest and easiest thing that supermarkets could do to cut their energy bills and reduce their carbon footprint? They all know the answer. Put doors on their fridges' (Pearce, 2009).

Reducing energy consumption in a chilled multi-deck cabinet is substantially different to reducing it in a frozen well cabinet (James et al., 2009). Improvements can be made in insulation, fans and energy efficient lighting but only 10% of the heat load on a chilled multi-deck comes from these sources compared with 30% on the frozen well. Research efforts are concentrating on minimizing infiltration through the open front of multi-deck chill cabinets, by the optimization of air curtains and airflows, since this is the source of 80% of the heat load. In frozen well cabinets reducing heat radiation onto the surface of the food, accounting for over 40% of the heat load, is a major challenge. Traditionally open well cabinets were used to display frozen products but increasingly multi-deck cabinets are used because of their increased sales appeal. The rate of heat gain in a multi-deck cabinet and consequently the energy consumption is much higher than in a well cabinet. Due to the increased costs of energy multi deck cabinets are now appearing on the market with double glazed doors that have to be opened to access the food on display.

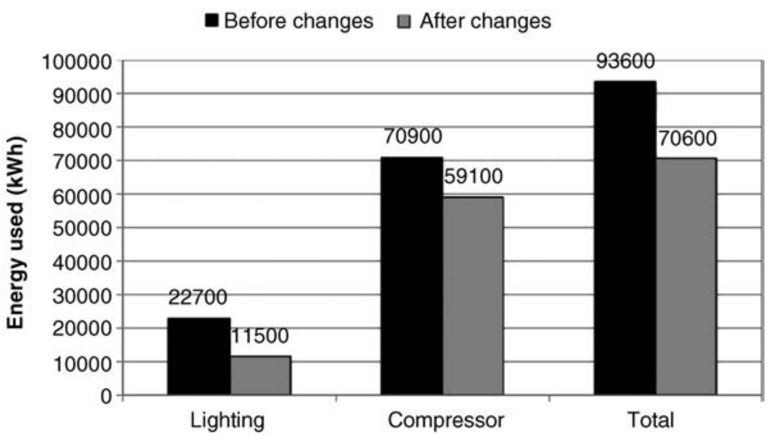

Figure 19.3 Energy used prior to and after installation of fibre optic lighting on retail display (adapted from Mitchell, 2006).

The performance of an individual display cabinet does not only depend on its design. Its position within a store and the way the products are positioned within the display area significantly influences product temperatures. In non-integral (remote) cabinets (i.e. those without built in refrigeration systems) the design and performance of the stores central refrigeration system is also critical to effective temperature control.

Mitchell (2006) measured the energy consumption of the lights and refrigeration system in a retail display prior to and after the installation of fibre optic lights. The projected data showed an annual energy savings of 11,200 kWh (49.3%) from direct lighting (Figure 19.3). Additionally, further analysis estimated an annual compressor energy savings of 11,800 kWh (16.7%). The estimated total annual energy savings was 23,000 kWh.

Studies carried out by the Refrigeration Technology and Test Centre (RTTC) (2009c) showed that retrofitting an old meat display cabinet with energy efficient lamps, ballasts and fan motors reduced the cooling load by 13% and the overall power consumption by 27%. Retrofitting a new more efficient meat display cabinet with electronic commutated fan motors (ECM) and a high efficiency coil reduced overall power consumption by 8% without affecting the meat temperature. Other studies carried out at the same test centre (RTTC, 2009d) looked at the effect of different food loading scenarios including: blocking of return air, overloading above load line, non-uniform loading and disturbing the air curtain. Interestingly the overall energy consumption was not significantly changed by any of the loading scenarios. However, with a fully blocked return air grill, average food temperatures rose by up to 3.4 °C and the maximum food temperature rose from 2.9 to 11.3 °C.

Sarhadian (2004) showed that by installing more energy efficient lighting and replacing integral retail display cabinets in a small food store, could produce significant reductions in energy usage. The total electricity demand was reduced by 18%, the refrigeration system by 22% while the overall illumination was increased by 40% and the power consumed by the lighting reduced by 22%.

19.2.6 Domestic storage

It has been reported that a ten-year-old refrigerator uses 2.7 times as much energy per litre of usable volume as a new A-class one (Carlsson-Kanyama and Faist, 2000). This has a clear effect on energy consumption. In Mexico Arroyo-Cabañas et al., (2009) evaluated the energy saving potential of replacing old, low efficiency domestic refrigerators with modern, high efficiency ones. They reported that total replacement in Brazil would save 4.7 TWh/year, which represents 33% of the annual total. In an example used by Carlsson-Kanyama and Faist, 2000, the energy use for a 10-year-old freezer, 0.029 MJ per litre net volume per day with only a 50% utilization was 0.058 MJ per litre per day. Assuming a storage time of 90 days, then the energy use is 5.2 MJ per litre food. Using a new A-class freezer (0.012 MJ per litre net volume per day) with a 90% utilization, the energy use during 90 days is only 1.2 MJ per litre. This is less than a fourth of the energy used in the first example, which shows the importance of both energy efficiency of the refrigerator and utilization. However, considerable energy is needed to produce a new domestic refrigerator so there will be an increase in emissions in the short term.

Energy labelling is a valuable tool in reducing energy use. Energy labelling of domestic refrigerators, combined with minimum requirements, has led to a reduction of 26% in energy consumption per refrigerator over ten years in the UK (Heap, 2001; DTI, 2002). In Brazil it was estimated that energy labelling of domestic refrigerators and freezers saved 1379 GWh in 2007 (Cardoso et al., 2010).

Several technological areas where improvements for efficiency enhancements are still possible are forced convection for evaporators and compressors; lower viscosity oils; reduction of temperature level inside the compressor; variable speed motors; linear compressors and improved insulation.

Some researchers (Estrada-Flores, 2008) have pointed out that the need for more energy-efficient domestic appliances will need to be balanced with the fact that food products will become more expensive and therefore, more valuable. Thus, consumers will demand that domestic refrigerators, freezers and other storage solutions maximize product shelf-life. Garnett (2008a) also argues that efficiency improvements also need to be set in the context of behavioural trends that are hurrying us in ever more refrigeration dependent directions. Back in 1970, over 40% of the UK population did not have a fridge,

and only 3% owned a freezer (Garnett, 2008b). Today, ownership of some sort of fridge-freezer combination is virtually universal in most of the developed world.

19.2.7 Refrigerants

About 20% of the global-warming impact of refrigeration plants is due to refrigerant leakage (March Consulting Group, 1998). However, it depends of course on the applications: for domestic refrigerators, for example, the figure is 2%; while for mobile air conditioning, the figure is 37%. Refrigerant leakage can be up to 15% per year in commercial refrigeration plants (Coulomb, 2008), and leakage varies greatly from one system to another.

The dominant types of refrigerant used in the food industry in the last 60 years have belonged to a group of chemicals known as halogenated hydrocarbons, for example, chlorofluorocarbons (CFCs) and the hydrochlorofluorocarbons (HCFCs). Scientific evidence clearly shows that emissions of CFCs have been damaging the ozone layer and contributing significantly to global warming. Consequentially the Ozone Depletion Potential (ODP), the Global Warming Potential (GWP) and the Total Equivalent Warming Impacts (TEWI) have become the leading criteria in the choice of refrigerants today (Duiven and Binard, 2002).

The retail sector, including supermarkets, is one of the largest users of F-gas (fluorinated greenhouse gas) refrigerants. In the UK, emissions due to leakage of HFC refrigerants from all types of stationary refrigeration was estimated to be equivalent to 1,740,000 tonnes of CO_2 in 2005, with leakage from supermarket refrigeration systems contributing 769 tonnes (AEA Technology, 2004).

Ammonia is the common refrigerant in large industrial food cooling and storage plants. It is a cheap, efficient refrigerant whose pungent odour aids leak detection well before toxic exposure or flammable concentrations are reached. The renewed interest in this refrigerant has led to the development of compact low charge systems, which significantly reduce the possible hazards in the event of leakage. Ammonia also has a role in more sensitive areas where a leak, however small and safe, is considered unacceptable, such as supermarkets. It can be used in remote plants as a primary refrigerant to cool secondary refrigerants such as water, brine or glycol. These secondary refrigerants can then be pumped round the stores to provide the cooling required in air conditioning units and chilled and frozen stores and display cabinets. However the energy consumption may be up to 10% higher than other systems (Duiven and Binard, 2002). Ammonia/Carbon dioxide cascade systems are showing great promise with energy consumption figures being reported to be either the same or even lower than conventional systems (Duiven and Binard, 2002).

Environmental groups, Greenpeace in particular, have championed the use of hydrocarbons, particularly propane and isobutane or mixtures of both, for domestic refrigerators and freezers. Studies have shown that propane or butane in the quantities required within domestic systems result in a minimal risk of fire or explosion, although there have been reports in the UK press of explosion problems with hydrocarbon fridges (Fox, 2009). Greenpeace (2009) claims that there are now over 400 million hydrocarbon refrigerators in the world today, and that of the 100 million domestic refrigerators and freezers produced annually globally between 35–40% of the production now use hydrocarbons. Due to concerns over the safety risk of the larger quantities of hydrocarbons required in commercial or industrial food refrigeration plants their use in these applications is less common. However, hydrocarbon use is expanding beyond domestic applications with the UK supermarket Waitrose claiming to be the first supermarket to develop propane-based refrigeration technology, which it claims will dramatically reduce its carbon footprint by 20% (Waitrose, 2009). It planned on introducing this technology to its new Waitrose Altrincham branch in 2010 and ‘in every new and major refitted branch thereafter’.

19.3 The impact of the cold-chain on climatic change

Energy is required to maintain the cold-chain and the generation of this energy contributes to CO_2 production and climatic change. In addition the manufacture and direct loss of refrigerant used in the refrigeration systems also contributes. However, it is difficult to obtain reliable data on the contribution either source actually makes.

Mattarolo (1990) estimated that 40% of all food requires refrigeration and that 15% of the electricity consumed worldwide is used for refrigeration. This 15% figure is in agreement with International Institute of Refrigeration estimates (Coulomb, 2008). Estrada-Flores and Platt (2007) estimated that the total energy spent in the Australian food industry to keep an unbroken cold-chain from farm to consumer is about 19,292 GWh/year, or 18 MtC (Million tonnes of Carbon). In the UK, food, drink and tobacco manufacturers use more energy than is used in iron and steel production (Department for Environment, Food and Rural Affairs, 2006). Around 14% of total energy consumption is used in producing and processing food (Department of Trade and Industry, 2002), with 11% of electricity consumed by the food industry, totalling 22.4 MtC for food and catering (Department for Business Enterprise and Regulatory Reform, 2005). The food and drink manufacturing, food retail and catering sectors are responsible for approximately 4% of the UK’s annual greenhouse gas emissions (Anon., 2007). With about 2.4% of the UK’s greenhouse gas emissions due to food refrigeration (although ‘embedded’

refrigeration in foods grown or manufactured and imported from overseas, could increase this figure to at least 3–3.5%) (Garnett, 2007). The Carbon Disclosure Project Report (Carbon Disclosure Project, 2006) states that worldwide food only accounts for 1% of total CO_2 emissions.

In addition, detailed estimates of what proportion of this is used for refrigeration processes in the cold-chain are less clear and often contradictory (James et al., 2009). Garnet (2008a) states that in the UK food and drink related refrigeration emissions (i.e. including refrigeration in supermarkets, catering outlets, pubs and cellars, staff catering and so forth) work out at 1.46 MtC, equivalent to 0.97% of the UK's CO_2 emissions, and refrigerant leakages contribution to the UK's total GHG emissions is also 0.97%. In addition Garnet states that 280,000 tC is used by refrigeration systems in food manufacture and 1.9 MtC in domestic refrigeration.

Looking at individual operations through the cold-chain and commodities provides some idea of which combinations contribute most to climate change.

19.3.1 Primary chilling and secondary cooling

Primary chilling is the first and most important stage of the cold-chain for a refrigerated food. The rate of temperature reduction often determines the subsequent safety and quality of the food. In primary cooling systems, the majority of the total heat load should be the product load since the purpose of a primary chilling system is to extract this load. The total product heat load is dependent on the type of food product, its initial temperature (at harvest or slaughter), the final temperature to which the product is required to be cooled to prior to storage, and the mass of the product that is being cooled. The rate of release of heat from the food is also a function of the chilling system used, its operating temperature(s) and the heat transfer coefficient(s) achieved.

Swain et al. (2009) calculated the energy required to cool different raw food materials using the overall weight of annual UK production multiplied by the enthalpy change required to reduce the temperature post harvest/slaughter to its recommended storage temperature. In the UK, milk is the raw material that requires the most cooling with an estimated energy value at least 2.5 times more than all the other major materials added together and over 4.5 times more than all types of meat combined. In addition to milk and meat the primary chilling of vegetables, especially potatoes, requires the extraction of substantial quantities of heat.

19.3.2 Transportation

Sea, air and land transportation systems are expected to maintain the temperature of the food within close limits to ensure its optimum safety and high

quality shelf life. It is estimated that there are approximately 1300 specialized refrigerated cargo ships, 80 000 refrigerated railcars, 650 000 refrigerated containers and 1.2 million refrigerated trucks in use worldwide (Heap, 2006). The type of transportation used will substantially affect the energy used. It has been estimated that the same amount of fuel can transport 5 kg of food only 1 km by personal car, 43 km by air, 740 km by truck, 2400 km by rail, and 3800 km by ship (Brodt et al., 2007). Refrigeration accounts for roughly 40% of the total energy requirement during distribution, making the distribution of frozen food around 1.7 times as energy-intensive as the distribution of groceries at ambient temperature (McKinnon and Campbell, 1998).

Air-freighting is used for high value perishable products, such as strawberries, asparagus and live lobsters (Sharp, 1988; Stera, 1999). However, foods do not necessarily have to fall into this category to make air transportation viable since it has been shown that 'the intrinsic value of an item has little to do with whether or not it can benefit from air shipment, the deciding factor is not price but mark-up and profit' (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2006). Air is the most intensive form of transport with the highest CO_2 emissions per tonne of the commercial transportation systems (AEA Technology, 2005; Department for Environment, Food and Rural Affairs, 2005; Garnett, 2008a). UK studies show that while less than 1% of all food consumed in the UK is carried by air it accounts for 11% of total food transport CO_2 (including car trips), 1.5% fruit and vegetables are carried by air but it accounts for 40% of the total CO_2 (or 50% of freight CO_2) used in transport of vegetables.

Over a million refrigerated road vehicles are used to distribute refrigerated foods throughout the world (Gac, 2002; Billiard, 2005). Freight transport consumes nearly 25% of all the petroleum worldwide and produces over 10% of carbon emissions from fossil fuels (Estrada-Flores, 2008). Food transport accounts for one quarter of all heavy-goods vehicle miles in the UK, with the average number of miles that food travelling doubling in 30 years (Department for Environment, Food and Rural Affairs, 2005). It has been reported in that in the US foods are typically transported over an average distance of 2100 km before arriving on the consumer's plate (Miller, 2001). A study by Nestlé demonstrated that transport generated roughly 15 kg of CO_2 emissions per tonne of product delivered. This represents approximately 10% of the total CO_2 generated during the manufacturing process (Carbon Disclosure Project, 2006).

Transport of food, consumed in the UK, accounted for an estimated 30 billion vehicle kilometres in 2002, of which 82% were in the UK (AEA Technology, 2005). Road transport accounted for most of the vehicle kilometres (Table 19.2), split between cars, HGVs (Heavy Goods Vehicles) and LGVs (Light Goods Vehicles). Food transport produced 19 million tonnes of carbon dioxide in 2002, of which 10 million tonnes were emitted in

Table 19.2 Transport emissions estimated for transporting food from its source to UK stores and on to consumers homes (adapted from AEA Technology, 2005)

Transport mode	CO_2 emissions as a proportion of total food transport emissions (%)	Transportation (tonne-km) as a proportion of total transportation (%)
(UK road total commercial)	39	35
UK road HGV	33	19
UK road private cars	13	48
Overseas road HGV	12	7
International by sea	12	0.04
International HGV	12	5
International air freight	11	0.1
UK road LGV	6	16
Overseas road LGV	2	5
Rail, inland waterways	Insignificant	Insignificant

the UK (almost all from road transport), representing 1.8% of the total annual UK CO_2 emissions, and 8.7% of the total emissions of the UK road sector (AEA Technology, 2005). The role of the consumer of this food should not be discounted either. It has been estimated that around one in ten car journeys in the UK are for food shopping (Department for Transport, 2007).

Improvements in energy efficiency would not only cut distribution costs, but also reduce atmospheric emissions. The use of diesel-powered refrigeration equipment substantially increases the level of emissions per tonne of product distributed. Unlike lorry tractor units, which have been subject to tightening EU emission standards, the refrigeration motors on much of the 'reefer' trailer fleet continue to produce high levels of noxious emissions per litre of fuel consumed (McKinnon and Campbell, 1998). The rise in supermarket home delivery services where there are requirements for mixed loads of products that may each require different storage temperatures is also introducing a new complexity to local land delivery (Cairns, 1996).

The concept of 'food miles' is clearly of concern to countries with well-established export markets, such as Australia and New Zealand. However, a comparison of dairy and sheep meat production by Saunders et al. (2006) concluded that New Zealand produced products for the UK market were 'by far more energy efficient' than those produced in the UK. This included the energy used in transportation. With production being twice as efficient in the case of dairy, and four times as efficient in case of sheep meat. This reflects the extensive production system in New Zealand compared with the UK and the proportion of energy used and carbon produced during the production of food rather than in its processing and transportation.

Table 19.3 Energy consumed by each cold store

Refrigeration plant	kWh/yr	kWh/yr/m^3	kWh/yr/m^2
Cold store 1	710,335	57.3	458.3
Cold store 2	652,573	71.1	710.6
Cold store 3	1,138,178	57.9	463.1

19.3.3 Storage

Following harvesting/production many foods are transported to centralized ‘cold stores’ (Europe) or ‘refrigerated warehouses’ (US) prior to distribution to retailers/end-users. Cold stores may be chilled or frozen and operate at a range of different temperatures depending on the product or customers requirements. When correctly used these facilities are only required to maintain the temperature of the product.

There is limited published data on energy consumption in cold stores (Duiven and Binard, 2002; Famarazi et al., 2002; Werner et al., 2006). The energy consumption of cold-stores depend on many factors, including the quality of the building, activities (chilled or frozen storage), room size, stock turnover, temperature of incoming product, external environmental conditions, and so on (Duiven and Binard, 2002).

FRPERC has carried out a comprehensive study of three large cold store complexes in the UK (James et al., 2009). The actual performances of the cold stores per cubic and square metre are shown in Table 19.3.

It is common practice in the frozen food industry to use refrigerated trailers as overspill storage space. In a survey of 1300 refrigerated trailers over a 48-hour period, it was found that roughly a fifth of their time was spent loaded and stationary (McKinnon and Campbell, 1998).

19.3.4 Catering

Refrigerated Commercial Service Cabinets (CSCs) are used to store food and/or drink in commercial catering facilities. There are approximately 500 000 units in use in the UK (Market Transformation Programme, 2006). The vast majority of the cabinets sold are integral cabinets (refrigeration system on board the unit). Most of the market is for chilled or frozen upright cabinets with one or two doors or under counter units with up to four doors. The average energy consumption for chilled cabinets is 2920 kWh per year and for frozen is 5475 kWh per year (Market Transformation Programme, 2006).

The limited published data on energy consumption of CSCs in use are shown in Figure 19.4. Although each cabinet type is of similar size and therefore can be directly compared in terms of functionality, there is a large difference in energy consumed by each type of CSC.

Figure 19.4 Energy consumed by different types of CSCs in different types of catering establishments.

There are over 4 million refrigerated vending machines in the USA consuming 12 billion kWh of electricity per year (Refrigeration Technology and Test Centre (RTTC), 2009a). They consume between 7 and 16 kWh per day, which is typically five times more electricity than a domestic refrigerator. Ambient temperature has a substantial affect on energy consumption. An 8 °C rise in ambient from 24 to 32 °C resulting in a 40% increase in energy consumption.

19.3.5 Retail

In 2002 it was estimated that there were 322 000 supermarkets and 18 000 hypermarkets worldwide and that the refrigeration equipment in these supermarkets used on average 35–50% of the total energy consumed in these supermarkets (United Nations Environment Programme, 2002). In a US survey of a store (RTTC, 2009b) 68% of its total annual electric use was attributed to refrigeration, with only 8% to heating, ventilation and air conditioning, and 23% to lighting. For a typical size food retail store, 3500 MWh of electrical energy will be consumed in a year, of which 2100 MWh can be due to the refrigeration systems (Evans et al., 2007). In the retail environment the majority of the refrigeration energy is consumed in chilled and frozen retail display cabinets (James et al., 2009).

19.3.6 Domestic

Domestic refrigerated storage is an often-unregarded part of the food cold-chain by the food industry. However, from an environmental point of view this

sector is important. There are approximately 1 billion domestic refrigerators worldwide (International Institute of Refrigeration (IIR), 2002). At present, most of these are in industrialized countries. However (as noted by Billiard, 2005), production in developing countries is rising steadily (30% of total production in 2000). When the environmental impact of these refrigerators is considered using a LCCP (Life Cycle Climate Performance) approach, the emissions of refrigerant in a domestic HFC-134a refrigerator represent only 1–2% of the total contribution to global warming while emissions due to energy consumption represent 98–99% (Billiard, 2005). Therefore, energy consumption is the most significant issue with regards to global warming. In a study on ketchup, Andersson et al. (1998) found that energy used in long-term storage in home refrigerators can dwarf energy use in any other sector of the ketchup life cycle by a factor of two or more, and fuel used for consumer shopping can be as much as fuel used in all other transportation earlier in the life cycle, on a per kg basis.

19.3.7 Overall

On the best available data, James et al. (2009) identified the top ten processes, excluding domestic systems, in the UK cold-chain in terms of energy saving potential as shown in Table 19.4. The saving potential within the top five consuming operations in the UK (retail, catering, transport, storage and primary chilling) was estimated to lie between 4300 and 8500 GWh/y in the UK.

As yet few other studies appear to have looked at the cold-chain. Work in Germany on the fish cold-chain found that retailing consumed over six times

Table 19.4 Best estimate of the top ten food refrigeration processes ranked in terms of their potential for total energy saving (basis of estimations provided on www.grimsby.ac.uk/documents/defra/usrs-top10users.pdf)

	Sector	Energy		Saving	
		000 t CO_2/y	GWh/y	%	GWh/y
1	Retail display	3100–6800	5800–12700	30–50	6300
2	Catering – kitchen refrigeration	2100	4000	30–50	2000
3	Transport	1200	4800	20–25	1200
4	Cold storage – generic	500	900	20–40	360
5	Blast chilling – (hot) ready meals, pies	20–330	309–610	20–30	180
6	Blast freezing – (hot) products	120–220	220–420	20–30	130
7	Milk cooling – raw milk on farm	50–170	100–320	20–30	100
8	Dairy processing – milk/cheese	130	250	20–30	80
9	Potato storage – bulk raw potatoes	80–100	140–190	~30	60
10	Primary chilling – meat carcasses	60–80	110–140	20–30	40

Table 19.5 Specific energy required (MJ/t) to chill, freeze and process (cutting and deboning) meat (adapted from Ramirez et al., 2006)

Product	Whole & chilled	Whole & frozen	Cut, deboned & frozen
Beef, veal and sheep	1390	2110	2866
Pork	2093	3128	3884
Poultry	3096	4258–5518	5014–6274

the energy of the next most energy intensive operation of spiral freezing (Meurer and Schwarz, 2003). While Ramirez et al., (2006) reported that the specific energy consumption required to produce frozen carcass meat was far higher than for chilled (Table 19.5). Further processing the meat to produced cut up and deboned products further increased the energy required. In Europe the amount of energy required to produce a tonne of meat has increased by between 14% and 48% between 1990 and 2005 (Ramirez et al., 2006).

19.4 Climate change impacts on the cold-chain

It is reported that, between 1900 and 2005, there was a 0.45 °C rise in average world temperature (Carbon Disclosure Project, 2006). The rate of rise appears to be increasing with a 0.1 °C rise in last nine years. Local rises can be much higher, in the UK in the first quarter of 2007 temperatures were on average 2.1 °C warmer than in the first quarter of 2006 (Department of Trade and Industry, 2007). However, such changes could be due to natural variability. In Australia (Commonwealth Scientific and Industrial Research Organization, 2001), it is estimated that global warming will cause temperatures to rise 0.4 °C to 2 °C by 2030, and 1 °C to 6 °C by 2070.

There is clear evidence that food poisoning in many countries is affected by seasonal changes, with a higher incidence in the summer and fewer cases during the winter (Bentham, 2002; Hall et al., 2002). Hot summers may produce particularly large increases in food poisoning. There is thus concern that a rise in global temperatures due to global warming will bring with it a subsequent rise in the incidence of food poisoning (Schmidhuber and Tubiello, 2007). High temperatures favour the multiplication of pathogenic micro-organisms in food. For example, multiplication of the salmonellas is strongly temperature dependent with growth occurring above about 7 °C and reaching an optimum at 37 °C (Bentham, 2002). Semenza and Menne (2009) state that colonization of broiler chicken flocks with campylobacter also increases rapidly with rising temperatures. The risk of campylobacteriosis is positively associated with mean weekly temperatures, although the strength of association is not consistent in all studies. Warmer summer temperatures and humid conditions can enhance the survival of microbes in the environment, leading to increased contamination of food, and increased risk of infection (Charron et al., 2005).

High temperatures may also affect infection rates in food animals, for example by the multiplication of bacteria in animal feed (Bentham, 2002). In addition, some seasonal behaviour may also exacerbate the risk of food disease transmission, such as outdoor barbequing, al fresco meals, and so on (Bentham, 2002; Charron et al., 2005). On farms, the microbial ecology may change with altered climate, potentially changing the species composition of pathogens and their infectivity to people (Charron et al., 2005).

A number of studies have investigated the direct relationship between environmental temperatures and the occurrence of food poisoning. D'Souza et al., (2003) found a significant positive association between mean temperature of the previous month and the number of salmonellosis notifications in the current month in five Australian cities, with the estimated increases for a 1 °C increase in temperature ranging from 4% to 10%, depending on the city. Kovats et al., (2004) found, on average, a linear association between temperature and the number of reported cases of salmonellosis above a threshold of 6 °C. The relationships were very similar in The Netherlands, England and Wales, Switzerland, Spain and the Czech Republic. While Fleury et al., (2006) found a strong association between ambient temperature and the occurrence of three enteric pathogens (Salmonella, pathogenic *Escherichia coli* and Campylobacter) in Alberta, Canada, and of Campylobacter in Newfoundland-Labrador. However, the relationships were not linear. For Alberta, the log relative risk of Salmonella, Campylobacter and *E. coli* weekly case counts increased by 1.2%, 2.2% and 6.0%, respectively, for every 1 °C increase in weekly mean temperature. For Newfoundland-Labrador the log relative risk increased by 4.5% for Campylobacter for every 1 °C increase in weekly mean temperature.

Some countries have made projections of the effect of climate change on the increase in cases of food poisoning. A UK report (Bentham, 2002) in 2001/2002 estimated that cases in the UK could rise by about 10 000 extra cases per year. A further revision of this report in 2008 (Bentham, 2008) considered that there were no grounds for revising that estimate. While an Australian report estimates that cases in Australia could rise to around 79 000 additional cases per year by 2050 (Department of Climate Change, 2009).

It is very clear from the microbiological data, that if the food industries' response to a 2 to 4 °C rise in ambient temperatures, were to allow a similar rise in the temperature of chilled food then food poisoning and spoilage would increase. It is an accepted crude approximation that bacterial growth rates can be expected to double with every 10 °C rise in temperature (Gill, 1986). Below 10 °C, however, this effect is more pronounced and chilled storage life is halved for each 2 to 3 °C rise in temperature. Thus the generation time for a pseudomonad (a common form of spoilage bacteria) might be 1 hour at 20 °C, 2.5 hours at 10 °C, 5 hours at 5 °C, 8 hours at 2 °C or 11 hours at 0°C (Harrigan and Park, 1991). In the usual temperature range for chilled meat, −1.5 °C to 5 °C, for example there can be as much as an eight-fold increase in growth rate

between the lower and upper temperature. Surveys of temperatures in chilled retail display cabinets show that temperatures can range from −1 °C to 16 °C (James and Evans, 1990; Evans et al., 2007), whilst mean temperatures in domestic refrigerators throughout the world range from 5 °C to 6 °C, with many operating at significantly higher temperatures (James et al., 2008). Thus, it is clear that the temperatures achieved in both retail display and domestic storage, need to be lowered rather than allowed to rise in the foreseeable future if food safety is not to be compromised and high quality shelf life assured. Keeping food at current or lower temperatures will result in an increase in the energy used by food refrigeration systems as ambient temperatures rise. Sarhadian (2004) measured the average power consumed by refrigeration equipment in a catering establishment in different ambient. Increasing the ambient temperatures from 17 to 25 °C resulted in an 11% increase in average power consumed.

In addition, if climate change were to result in higher levels of microorganisms being present on meats and produce prior to processing it could have a significant effect on the shelf-life or storage requirements of chilled foods. With higher numbers, fewer doublings are required to reach a spoilage level of *ca* 10^8 organisms/cm^2. For example, at a specific temperature, starting with one organism/cm^2, 27 doublings would be needed; while for an initial load of 10^3 organisms/cm^2, the number of doublings is reduced to 17. Thus lower storage temperatures may be needed to maintain required shelf-lives.

Currently food is frozen to and generally maintained at a temperature below −18 °C throughout storage, transport, retailing and domestic storage. In the case of frozen food, if the food industries response to a 2 to 4 °C rise in ambient temperatures were to allow a similar rise in the food temperature, then food poisoning and spoilage would not increase. However, if this were universally adopted then the high quality storage life of many temperature sensitive food products including ice cream, frozen desserts, oily fish and tuna would deteriorate.

19.5 Sustainable refrigeration systems in the cold-chain

19.5.1 Alternative refrigeration technologies

Tassou et al., (2009) reviewed the potential of new/alternative refrigeration technologies to reduce energy consumption in food refrigeration. Their review concentrated on seven systems: Trigeneration, Air Cycle, Sorption – Adsorption Systems, Thermoelectric, Stirling Cycle, Thermoacoustic and Magnetic refrigeration.

Ground heat exchangers for heating and cooling and ejector refrigeration were also considered. Characteristics and potential applications of these systems are summarized in Table 19.6.

Table 19.6 Characteristics and applications of new/alternative refrigeration technologies

Technology	State of development	Cooling/refrig. Capacity of presently available or R&D systems	Efficiency/COP of presently available or R&D systems	Current/Potential application area(s)
Trigeneration	Large capacity bespoke systems available. Smaller capacity integrated systems at R&D stage.	12 kW to MW	Overall system efficiency 65-90%. Refrigeration system COP: 0.3 at −50 °C 0.5 at −12 °C	Food processing; cold storage; food retail
Air Cycle	Bespoke systems available.	11 kW to 700 kW	0.4–0.7	Food processing; refrigerated transport
Sorption-Adsorption	Available for cooling applications >0 °C. Systems for refrigeration applications at R&D stage.	35 kW to MW	0.4–0.7	Food processing; cold storage; retail; refrigerated transport
Ejector	Bespoke steam ejector systems available.	Few kW to 60 MW	Up to 0.3	Food processing; refrigerated transport
Stirling	Small capacity 'Free' piston systems available. Larger systems at R&D stage.	15 W - 300 W	1.0–3.0	Domestic refrigerators; vending machines; refrigerated cabinets
Thermoelectric	Low cost low efficiency systems available.	Few Watts to 20 kW	0.6 at 0 °C	Hotel room mini bar refrigerators; refrigerators for trucks, recreational vehicles; portable coolers; beverage can coolers
Thermoacoustic	R&D stage. Predicted commercialisation: 5–10 years.	Few watts to KW capacity	Up to 1.0	Domestic and commercial refrigerators, freezers and cabinets
Magnetic	R&D stage. Predicted commercialisation 10 plus years from now	Up to 540 W	1.8 at room temperature	Low capacity stationary and mobile refrigeration systems

The majority of trigeneration systems in the food industry are large plants in the MW range in food factories where bespoke ammonia plant is linked to gas turbines, or internal combustion engines. More recently, the application of trigeneration has been extended to supermarkets with a very small number of installations in the USA, the UK and Japan.

Air cycles generate high air temperatures, typically of over 200 °C, that can be used in combination with the low temperatures to integrate cooking and refrigeration processes. In the food sector air cycle technology can be potentially applied to rapid chilling and/or freezing (including air blast, tunnel, spiral, fluidized bed and rotary tumble equipment); for refrigerated transport (trucks, containers, rail freight, ships, air cargo); and for integrated rapid heating and cooling (cook-chill-freeze or hot water/steam raising and refrigeration).

The application of sorption-adsorption systems in the food sector is likely to be in areas where waste heat is available to drive the adsorption system. Such applications can be found in food factories and transport refrigeration.

Current applications of thermoelectric refrigeration in the food sector include: hotel room (mini-bar) refrigerators; refrigerators for mobile homes, trucks and cars; portable picnic coolers; wine coolers; beverage can coolers; drinking water coolers. Other potential future applications include domestic and commercial refrigerators and freezers, and mobile refrigeration and cooling systems.

Stirling cycles have been evaluated experimentally for application to domestic and portable refrigerators and freezers as well as vending cold beverages. Values of COP between 2 and 3 have been reported for temperatures around 0 °C, and values around 1 for temperatures approaching −40 °C.

Magnetic refrigeration has the potential for use across the whole refrigeration temperature range, down to cryogenic temperatures but it is anticipated that the first commercial applications will be for low capacity stationary and mobile refrigeration system.

In addition solar powered, hydrogen and geothermal refrigeration may have applications in the food cold-chain. Solar powered refrigeration systems capable of providing temperatures as low as −23 °C have been demonstrated (Le Pierrès et al., 2007). Metal hydrides absorb large amounts of hydrogen gas and provide significant cooling when hydrogen gas is removed from them. Conversely, when hydrogen is added to a hydride, heat is liberated. In the HyFrig system invented by Dr Feldman of Thermal Electric Devices a compressor is used to pump hydrogen into one of two finned hydride reactors, while drawing it off the other. As a result heating and cooling is produced. Hydrogen is the most abundant element in the universe and poses no environmental threat. It is claimed that the system could be 15 to 50% more efficient than conventional systems. The total cost of a hydride heat pump is claimed to be less than £500 per ton of cooling. Feldman feels that the system is well suited to solar powered refrigerators and for electrical vehicle air conditioning.

Geothermal cooling systems circulate water below ground through a series of pipes where it is cooled by the surrounding earth and subsequently pumped back to the surface (Masanet et al., 2007). Where feasible, such systems can replace or augment existing refrigeration systems, leading to significant energy savings. In 2005, Aohata Corporation, a jam manufacturer in Japan, began operating a new geothermal cooling system that provided its facility with 260 kW of additional cooling capacity. The company reported that the geothermal cooling system uses only about 25% of the electricity required by a traditional refrigeration system (Japan for Sustainability, 2006).

It is expected that many of these novel refrigeration technologies will find niche application in food refrigeration operations in the future. For example, one commercial company 'Camfridge' (http://www.camfridge.com/) hopes to have a commercial magnetic refrigerator available in 2014. However, none appear to be likely to produce a step change reduction in refrigeration energy consumption within the food industry within the next decade.

19.5.2 Energy balance

A more first principles approach to operations in the cold-chain is far more likely to achieve step change in the reduction of energy. The whole purpose of a food factory is to take a supply of raw materials and packaging and transform them in the most cost efficient manner into a finished packaged product. The first stage in the design or optimization should be to carry out an energy balance comparing the heat energy in the raw material prior to processing with that in the finished product. This immediately shows whether heat has to be added or subtracted during the operation. This information should be a key element in governing the design of a new process or pointing to where energy can be saved in an existing operation.

The following is an example of using the 'heat balance' approach on a whole food factory. In the fish industry there are many companies that fillet and portion whole fish. These fillets and portions can either be bulk packed for further processing or are more commonly used to make up consumer packs. The raw material intake for such companies is typically a range of frozen and chilled whole fish and the output a chilled product. In addition during the process waste material in produced, primarily the head and bony carcass, and sometimes the offal if the raw material has not been previously gutted.

A typical factory will have a raw material input of 350 tonnes of whole frozen fish at −20 °C and 125 tonnes of chilled whole fish in melting ice at 0 °C. Its output will be 400 tonnes of finished product at 3 °C and 75 tonnes of waste material at 12 °C. During processing the heat energy in the food and waste had therefore increased from 32 500 million kJ to 121 525 million kJ. However, the majority of the energy consumed by the factory will be to maintain refrigeration facilities.

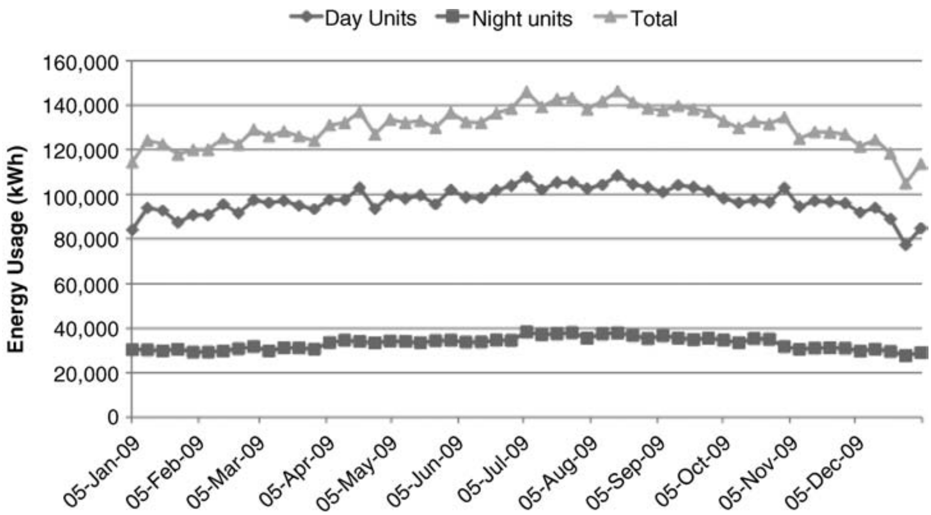

Figure 19.5 Electrical energy consumption per week in 2009.

During processing the material will be kept on site in chilled and frozen storage rooms until required. The frozen fish will be thawed prior to loading on the filleting line. The chilled fish will be separated from the ice used in transport before being processed directly. After filleting/portioning the fish will be packed in individual consumer packs. Normally both the filleting/portioning and packaging halls will be refrigerated and held between 8 and 10 °C. After leaving the packing hall the individual packs will be consolidated on pallets and kept in a chilled dispatch store operating at 0 to 3 °C prior to transportation to retail distribution centres.

The total electrical energy used per week by a typical site over a year is shown in Figure 19.5. The average electrical energy consumed was 130 500 kWh per week and ranged from a maximum of 146 000 kWh in one week in August to a minimum of 105 000 kWh in one week in December.

An analysis of weekly throughputs of fish processed produce a poor relationship with the electrical energy consumed. Weeks of very high production in response to retailers operating special promotions do not correspond to times of high-energy usage. At a typical production rate of 400 tonnes per week electrical energy use ranged from 340 to 430 kWh per tonne of fish produced. In the peak production week of 730 tonnes this dropped to under 200 kWh per tonne produced. The energy cost per tonne of product produced ranged from £14 to £38 a 2.7-fold difference in costs.

Using the limited amount of sub-metering installed in the factories plus direct instantaneous measurement of electrical consumption, length of time in use data and controlled trials a typical breakdown of the main refrigeration loads in a typical factory has been produced (Table 19.7).

Table 19.7 Refrigeration loads (kW) in factory

Product load	Negative		
	Direct	Refrigeration	Total
Lighting	70	35	105
Fans	72	36	108
Defrosts	27	13	40
People	0	47	47
Filleting and packaging plant	80	40	120
Infiltration		900 to 2000	

As already discussed the total product load in a typical factory is negative since the final product is warmer than the raw materials when received. In a refrigerated area, a term that currently covers the total factory with the exception of offices and changing rooms, the energy used is paid for in two ways. The direct energy used to provide the lighting, drive the fans, and so on, and the extra refrigeration required to extract the heat generated by these processes.

For much of the year the largest load is heat infiltration through the structure and external doors. A typical factory is 100 m long, 30 m wide and has a pitched roof ranging from 10 to over 15 m in height. All the factories surveyed were over 10 years old and had been extended in various phases. Many different types of insulation had been used at varying thicknesses. Other main heat sources that have to be removed by the refrigerated systems come from the processing plant, fans, lighting, defrosts and people.

A staged approach can be used to reduce the main heat loads and refrigeration/energy uses.

Infiltration – Depending upon the time of the year and the outside ambient conditions the overall heat infiltration that has to be removed by the refrigeration systems ranges from 900 to 2000 kW. Three hundred tonnes of densely packed fish could be contained in a cube with 6.7 m sides. If this was enclosed within an insulated structure with 7 m sides made of 15cm thick insulated panels the rate of heat infiltration into fish at 0 °C from an outside ambient of 30 °C would be just over 3 kW. We do not suggest that it would be at all practical or feasible to operate with all the fish in one densely packed mass. However, the 300 to almost 700-fold difference between the theoretical mean infiltration and the typical case should stimulate discussion. Increasing packing densities, reducing free space around fish in refrigerated areas and increasing insulation could dramatically reduce refrigeration loads.

Filleting and packaging halls – Currently filleting and packaging halls are refrigerated often with large numbers of separate evaporator units. Air at 8 to 10 °C is directed over the fish being filleted at localized velocities as high as 1.5 to 2.0 ms^{-1} in the belief that the refrigerated air will keep the fish cold. The rate

of heat input into a unit area on the surface of fish in air is governed by the surface heat transfer coefficient multiplied by the temperature difference between the surface and the ambient. In still air ($<0.2\,\mathrm{ms^{-1}}$) the heat transfer coefficient will typically be $7\,\mathrm{Wm^{-2}K^{-1}}$ and at 1.5 to $2.0\,\mathrm{ms^{-1}}$ around $21\,\mathrm{Wm^{-2}K^{-1}}$. In the UK for much of the year the ambient temperature is below 20 °C so the heat input into the fish will be less when surrounded with still ambient air than refrigerated moving air. To minimize refrigeration loads in filleting and packaging halls it is therefore better to create areas of still air around the exposed fish and design the system so that the exposure time is restricted to the minimal possible. Under these circumstances it should be possible to operate the areas under ambient, non-refrigerated conditions.

Evaporator fans – Currently the evaporator fans and heat generated account for approximately 15% of the total electrical power consumed. Minimizing the use of refrigeration except in areas where there is a need to actively remove heat from the food being processed will reduce the number of evaporator coils and consequently fans. From the data gathered, with few exceptions, all the refrigeration systems appear to operate 24 hours per day with the evaporator fans only switching off during defrost periods. There appears to be no obvious distinction between their operation when processing is taking place and when there is no activity. In operations where heat is extracted from food then achieving high air velocities over the food during the start of the cooling operation is critical. However, control systems should be introduced to reduce fan speeds when the surface temperature is close to that of the environment and maintaining minimal air speeds when no heat is being extracted.

Lighting – The factories operated with high levels of illumination throughout all the processing halls and refrigerated storage systems. People need light to be able to operate safely and efficiently. However, fish and many other foods keep their colour better in the cold and dark. It should not be exposed to the light or to the heat generated by the lighting. Replacing current fitments with low energy ones and installing intelligent control systems can significantly reduce heat loads.

Defrosts – The defrosts and heat generated account for approximately 7.5% of the total electrical power consumed. Minimizing the use of refrigeration except in areas where there is a need to actively remove heat from the food being processed will reduce the number of evaporator coils and the need for defrosts. In many areas the use of larger more efficient evaporator coils to operate at temperatures close to and even above 0 °C would remove or significantly reduce the need for defrosts.

People – It is impossible to operate a food-processing factory without people. However, the heat loss from a person in a refrigerated area at 0 °C is twice that of the same person working in an ambient of 20 °C. At both temperatures creating a 'still' air situation around the person will reduce the rate of heat loss into the environment. Just refrigerating the surface of the food

being processed while keeping the working space at a higher temperature will both reduce energy consumption and improve productivity.

'Negative' heat loads – In a typical factory energy is used to aid thawing of frozen raw material and often to melt waste ice prior to disposal. In one case a 100kW heater system was used to melt waste ice. Using the thawing raw material and waste ice to cool ambient air could significantly reduce the need for mechanical refrigeration.

Overall – Calculating an overall heat balance for a process in the cold-chain will provide a target for the overall energy required. Systematically identifying and reducing all the major heat load sources will substantially move towards the theoretical target and aid the development of a sustainable operation.

19.6 Conclusions

Any noticeable increase in ambient temperature resulting from climatic change will have a substantial effect on the current and developing food cold-chain. A rise in temperature will increase the risk of food poisoning and food spoilage unless the cold-chain is extended and improved. The little data that is available suggests that currently the cold-chain accounts for approximately 1% of CO_2 production in the world. However this is likely to increase if global temperatures increase significantly.

Energy efficiency is increasingly of concern to the food industry mainly due to substantially increased energy costs and pressure from retailers to operate zero carbon production systems. Reducing energy in the cold-chain has a big part to play since worldwide it is estimated that 40% of all food requires refrigeration and 15% of the electricity consumed worldwide is used for refrigeration.

Simple solutions such as the maintenance of food refrigeration systems will reduce energy consumption. Repairing door seals and door curtains, ensuring that doors can be closed and cleaning condensers produce significant reductions in energy consumption. In large cold storage sites it has been shown that energy can be substantially reduced if door protection is improved, pedestrian doors fitted, liquid pressure amplification pumps fitted, defrosts optimized, suction liquid heat exchangers fitted and other minor issues corrected.

New/alternative refrigeration systems/cycles, such as Trigeneration, Air Cycle, Sorption-Adsorption Systems, Thermoelectric, Stirling Cycle, Thermoacoustic and Magnetic refrigeration, have the potential to save energy in the future if applied to food refrigeration. However, none appear to be likely to produce a step change reduction in refrigeration energy consumption within the food industry within the next decade.

The first stage in the design process should be to calculate the energy balance between that in the raw materials and packaging that enter a process and that in the product leaving. In examples such as those considered in this article where the raw materials are predominantly frozen and the finished

product chilled then the overall refrigeration product load will be negative. Where the raw materials are predominantly chilled or at ambient and the finished product frozen then the refrigeration product load will be substantial. In other cases such as bakeries the raw materials and the dispatched product can be at the same temperature and the overall refrigeration product load zero. In the future care should be taken to use the 'negative' heat and reduce heat loads throughout the individual processes and the total cold-chain.

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Section 4

Food Distribution and Consumption

20 National and International Food Distribution: Do Food Miles Really Matter?

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20.1 Introduction

Numerous tools have been brought to bear in helping study the problems of sustainable agriculture, with the chosen method often primarily depending on the way sustainability is viewed and the background of the investigator (Leach, 1976; Cormack and Metcalfe, 2000; Carlsson-Kanyama, 2003; Pretty et al., 2002; Rees, 2003; Lewis et al., 1997; Bailey et al., 1999). As the environmental impacts of global agro-food systems have been exposed (Conway and Pretty, 1991), the concepts of 'local food' and 'food miles' were promoted as powerful polemical tools in policy discourses built around sustainable agriculture and alternative food systems. Both are appealing to public opinion in their apparent simplicity of application and have demonstrated the fluidity to be used in different contexts as the alternative food debate has progressed and changed. There has been a strong tendency to assume that local food is a solution to the problem of food miles. Local food both pre-dates food miles as a concept and, as a consequence, to some extent, helps to configure the conceptualization of food miles. Originally the environmental impact of food miles was broadly conceptualized (SAFE Alliance, 1994; Raven and Lang, 1995; Subak, 1999). The reduction of food miles was seen as an aspect of making more explicit the links between

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particular foods and particular natures, a re-territorialization or re-spatialization of food production which begins to reverse the aspatialities which are, or were, an intrinsic part of a globalized food order. This was based on a growing realization that the properties of food are 'natural' and that the heterogeneity of edaphic conditions gives rise to varied natures represented in varied foods and their distinctive provenance. To reduce food miles implied the need for food systems grounded in local ecologies and responsive to consumer demands for quality food (Murdoch et al., 2000), hence the growing literature on the benefits of a more localized food supply system (Sage, 2003; Morris and Buller, 2003; Cowell and Parkinson, 2003).

More recently however, food miles have been linked much more explicitly, and in some cases solely, to carbon accounting and the climate change debate (Jones, 2001; Pirog et al., 2001; Smith and Smith, 1997; Lal et al., 2004). In some ways this has served to radically shift the food miles argument away from sustainable agriculture production systems *per se* to food distribution and retailing and, in particular, the use of carbon in transport. In their influential report to Defra on the validity of the concept, AEA Technology (2005) largely focus on CO_2 emissions as the key indicator of sustainability, and operates with a correspondingly narrow conception of environmental sustainability and virtually no sense of social and economic sustainability at all. AEA provides a series of case studies on food miles which focus on energy and carbon emissions, for example comparing tomatoes grown in the UK to those imported from Spain, with no attempt to place this within a wider conceptualization of sustainability. Defra's Food Industry Sustainability Strategy published in 2006 takes a somewhat broader approach but still gives considerable salience to the role of transport in carbon emissions in marked contrast to the breadth of its earlier Farming and Food Strategy (Defra, 2006). Alongside the concern at the narrowing of the sustainability agenda brought about by the focus on food miles is an equally important concern at the crude nature of the calculations used to assess carbon emissions in most studies hitherto. AEA's tomato case study is illustrative. Basically it amounts to a balancing out of the energy used in production (less in Spain, because of the climate, than in Britain) against the extra energy used in the transport to Britain. Such a simplistic approach masks the very real differences between the contrasting production and distribution systems.

Given the interest in food miles, organic production, localism and carbon emissions from energy use, the comparison is highly topical (Seyfang, 2006; Ilbery and Maye, 2005; Hinrichs, 2003; Rigby and Caceres, 2001; Morgan and Murdoch, 2000; Tait and Morris, 2000). The first part of this chapter will concentrate on the carbon emissions from the use of fossil fuels during the storage–distribution–retail chain for the case of organic vegetables. In particular, we make a comparison of the relative emissions from a system based on large-scale growing, bulk cold storage, mass distribution to regional hubs, then home delivery, with the much simpler case of a hypothetical small local farm

shop. This allows us to discover where in the large-scale system most emissions occur, thereby indicating for future work in the likely areas of policy and management that might reduce these emissions through energy efficiency and changes in working practices, and to compare the emissions arising from the food miles generated by both approaches.

In the second part of this chapter we question the value of using the concept of food miles as a driving force for changing purchasing behaviour by either the customer or the purchasing department of a retailer taking international transport into consideration. We will first make a comparison between food miles as traditionally applied and a method based on carbon emissions, not just distance. Two ways of influencing behaviour are then demonstrated. One attempts to influence the customer by informing them of the carbon emissions of alternative products to make them switch to a more sustainable alternative when making an on-line purchasing decision (e.g. a vegetable box low in imported fruit items against one high in such items). The other influences the actions of bulk purchasers within a retailer by giving them information on the carbon emissions of various alternatives (e.g. tomatoes from France rather than Spain).

Finally, it must be said that the question of sustainability in food production and distribution is obviously far wider than of emissions from fossil fuel use, and includes questions of water pollution, rural economics, landscape amenity and a host of others (Bollman and Bryden, 1997). As Table 20.1 shows, the

Table 20.1 The negative externalities of UK agriculture (year 2000). For comparison the UK's GDP in 2005 was around £1.2T (adapted from Pretty et al., 2005)

Source of adverse effects	Actual costs from current agriculture (£ M yr_1)	Costs as if whole of UK was organic (£ M yr_1)
Pesticides in water	143.2	0
Nitrate, phosphate, soil and cryptosporidium in water	112.1	53.7
Eutrophication of surface water	79.1	19.8
Monitoring of water systems and advice	13.1	13.1
Methane, nitrous oxide, ammonia emissions to atmosphere	421.1	172.7
Direct and indirect carbon dioxide emissions to atmosphere	102.7	32.0
OV-site soils erosion and organic matter losses from soils	59.0	24.0
Losses of biodiversity and landscape values	150.3	19.3
Adverse effects to human health from pesticides	1.2	0
Adverse effects to human health from microorganisms and BSE	432.6	50.4
Total	£1514.4	£384.9

external costs of agriculture are not minor. However, by restricting the analysis it is easier to address in a quantitative manner one of the questions of most interest to the public, and one in which, through their purchasing decisions, they have the ability to effect change.

20.2 Food miles and national food distribution

20.2.1 Traffic, shopping and home delivery studies

Over the last decade there has been a rapid growth in home delivery for grocery and other items; however, travel for food and household items still represents 40% of all shopping trips by car, and 5% of all car use (Cairns, 2005) (see Table 20.2), equating to over 16 billion vehicles km per annum. There is therefore pressure to reduce the possible congestion to which this gives rise and reduce the resultant carbon emissions. This then begs the question of whether a further growth in home delivery is likely to reduce congestion/emissions or exacerbate them.

There has been a large amount of research on the environmental impacts of home delivery (Handy and Yantis, 1997; Romm et al., 1999; Transport en Logistiek Netherland, 2000; NERA, 2000; Browne et al., 2001; Hopkinson and James, 2001; Mokhtarian and Salomon, 2002), and Cairns (2005) has produced an excellent review of this and other research. Home shopping itself can be seen as one of many "soft" policies to reduce traffic growth alongside initiatives such as school travel plans, car sharing and teleworking.

In the UK, groceries account for 46% of total retail spending and the market is dominated by a few major chains (Tesco, Sainsbury, Asda and Morrisons) with 68% of customers describing these as the source of their "main grocery shopping" (Mintel, 2003). A similar position is reported in other developed countries. It is known that grocery shopping is a frequent activity, with over half of households undergoing a major food shop once a week and 60% of these are dedicated journeys not linked to other activities such as travel to work (Mintel, 2003; Cairns, 1995; Cairns, 2005).

Table 20.2 National Travel Survey data about personal travel for shopping in the UK, 1998–2000 (Cairns, 2005)

Shopping trips primarily for:	Food	Non-food
Average trip distance (km)	4.8	9.0
Average number of trips per person per year	122	96
Average car/van driver travel generated per person per year (km)	290	400
Per cent of all car/van driver-km travelled per person per year 5.1	7.0	

Source: Data from the National Travel Survey – an annual survey of approximately 9400 households designed to be representative of the UK, with results aggregated into 3-year bands for improved data reliability (DTLR, 2001 as reported in Cairns, 2005).

There have been three main studies of the impact of grocery home deliveries on traffic using computer simulations (Cairns, 1996; Palmer, 2001; Punakivi et al., 2001; Punakivi and Holmstrom, 2001; Punakivi and Saranen, 2001; Punakivi and Tanskanen, 2002). These have used computer software to model the routes taken by householders to shops and of home delivery vehicles, and then compare the total length driven, given various assumptions. The results from these studies indicate that home delivery may well result in lower carbon emissions.

For example, in a study by Cairns (1996); it was concluded that:

1. Even with a small number of customers and vans that can only carry a few loads of shopping, there are likely to be reductions in motorized travel of 70% or more per shopping load if customers no longer drive to the shops but have their shopping delivered instead from the same store by a fleet of delivery vans.
2. As more customers shop from home, travel savings per shopping load are likely to increase as it is possible to schedule deliveries more efficiently.
3. The effect on overall travel for food shopping will be determined largely by the level of take-up of home shopping services.

However, Cairns' study assumed that the origin of the groceries, whether home delivered or picked up by the consumer, was the same: the nearest supermarket (this is not the assumption used in the work of Palmer, 2001 or Punakivi et al., 2001). In our case we have additional transport from the source of production and from the hub. We are also interested in other issues apart from traffic, namely emissions from vehicles, and energy use in chilled storage. Another difference is that Cairns assumed a maximum of 20 customers were served by one journey of the delivery van (Punakivi et al., 2001 assumed a maximum of 60). In our case the mean capacity of the vans is 80 customers.

Punakivi concluded that travel savings per shopping load could be substantial (50–70%) if a switch to home delivery is made, and that greenhouse gas emissions (from transport) could be reduced by between 17.7% and 87.2%.

There have also been a series of smaller pieces of work. Farahmand and Young's (1998) studied a single 2500 m^3 food store, showed that a 10% replacement of the assumed 450 shopping trips during the peak pm hours by home delivery (using five vans with nine loads each) would lead to 320 car-km being replaced by 43 van-km, a reduction of 87%. In a study of an expanding suburb of Stockholm, Persson and Bratt (2001) found that the percentage reduction in total grocery traffic (compared to 0% home delivery) might be between 20% and 24% if half the community engaged in home grocery shopping for their main shop.

Other studies of note are Murto (1996); Orremo et al. (1999) and Freire (1999). All reported that overall traffic levels would fall if home delivery became common.

20.2.2 A case study of carbon emissions

The work reported here is somewhat different to that covered in the above studies. Apart from the need mentioned above to include other sources of emissions, no data are available on what fraction of trips to a local farm shop are solely for the purchase of groceries, that is, are not chained. It would therefore seem unfair to assume that the likely reduction in vehicle movements from home shopping is on a one-for-one basis. For small farm shops there is also little data on the size of their catchment areas, so estimating greenhouse gas emissions from such trips is difficult. For these reasons, it was decided to use a comparative metric and to estimate the maximum distance, M_d, a person could travel such that their emissions are likely to be less than those emanating from the cycle of chilling, mass-transport, chilling and home delivery for the large-scale organic box system. As was stated above, any emissions from the operation of the farm shop have not been included; M_d is therefore likely to be an overestimate.

From M_d we can infer the maximum distance customers should consider travelling by car to a farm shop, rather than considering home delivery from a major supplier. In the case of chained journeys, M_d represents the additional distance a customer should consider travelling out of their way. As will be explained below, M_d is calculated assuming average UK car fuel efficiencies and emission factors.

Our large-scale system consists of short-term mass cold storage, mass road transport to a regional hub, short-term mass cold storage once more and home delivery via dedicated light duty vehicles (Figure 20.1). The comparison system consists of short-term storage at ambient temperature and purchase on site by the customer (Figure 20.2). In both cases most goods are assumed to have been produced on-farm and for goods that are not, for example bananas, both are assumed to have similar resultant carbon emissions, that is, they are sourced and transported in a similar way.

Annual energy consumption data (for 2006) were obtained from one of the UK's largest mass distribution based growers and suppliers of organic vegetables (Riverford) for all the sources shown in Figure 20.1. The cold storage, box packing and office premises are based at one location in the south-west of the UK with the majority of produce grown on surrounding land or nearby. Approximately 15% (by weight) of produce comes from other UK producers and 15% from overseas with a strict 'no air freight policy'. Once packed, boxes are transported by HGV to refrigerated 'hubs'; locations are accessed by one to six franchisees who then collect and distribute the boxes from the hub to customers in the local area. Over 32 000 boxes are shipped per week to

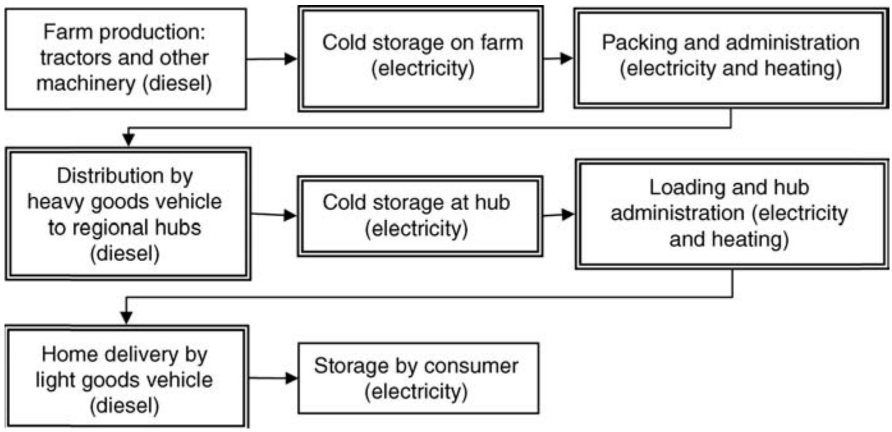

Figure 20.1 Main sources of fossil fuel related carbon emissions and flow of product for the large-scale system. Only those with double borders are considered and used to form Md.

51 franchisees operating in the south of England each making five or six different delivery rounds in a week. Information was calculated around the business metric of energy use 'per box' or delivery, rather than 'per kg of produce'. Electricity, gas and heating oil use data were derived from billing information for the farm site (including packing, cold storage and administrative operations). Energy use in distribution was based on surveying the HGV carriers, intermediate cold store bills and final distribution LGV drivers. The HGV carriers reported an average per-box round trip of 0.25 miles (0.40 km), or 1300 boxes per lorry, and a recorded fuel efficiency of 9.9 mpg (3.5 km/l); this was converted into CO_2 emissions using standard factors (Carbon Trust, 2006). This figure could be more accurately assessed in future work by more in-depth surveying. Electricity bills for nine of the 18 regional hubs were assessed to provide a figure showing the average use of electricity per box across all hubs. Information for the final distribution stage was gathered by surveying 24 of the 51 franchisees each of whom operate between one and seven vans (carrying around 80 boxes per van); the survey collected average distance travelled, fuel used and number of box deliveries per week. Fuel type was also gathered and showed vans to be predominantly run on diesel with a couple using petrol or LPG. Average energy input and CO_2 emissions per box

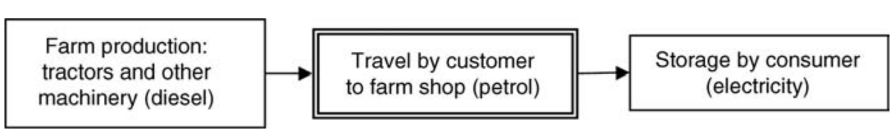

Figure 20.2 Main sources of fossil fuel related carbon emissions and flow of product for the small-scale system. Only those with double borders are considered and used to form Md.

were calculated based on standard factors for the appropriate fuel types (Carbon Trust, 2006).

The hypothetical small-scale system has no emissions connected to cold storage, regional hubs, HGVs or LGVs; carbon-wise it is therefore at a natural advantage. Furthermore, here we assume there are no meaningful emissions resulting from the operation of the farm shop or its administration. This is, as with the total lack of any cold storage, highly optimistic. As we consider any emissions from production on the farm, or eventual storage by the customer equal in both cases, the only source to be considered for the small-scale approach is that from the customer's journey to and from the farmshop.

The following assumptions were made:

1. Emissions were measured solely in terms of CO_2. However, as soil and animal emissions have been ignored, the contributions from other greenhouse gases are expected to be low.
2. The following standard emission factors were used for the conversion from fuel volume to $kgCO_2$. Energy content of diesel = 10.7 kWh/L, carbon emission factor for diesel = 0.25 (0.24 petrol) $kgCO_2$/kWh, electricity 0.43, natural gas 0.19 (for LPG used in some vans emissions is 0.21 $kgCO_2$/kWh) (Carbon Trust, 2006).
3. Calculation of energy use per box was based on electricity & heating fuel use and total box sales for 2006.
4. Use of diesel/LPG in lift trucks at farm and hubs has not been accounted for: this is expected to be minimal however.
5. M_d was calculated for a round trip in a petrol car that has carbon emissions equivalent to the current UK average of 0.210 $kgCO_2$ per km (i.e. 10.97 km/l, or 31 miles per gallon) (Dept. for Transport, 2006).
6. The quantity of produce purchased by a box scheme customer or a farm shop customer is the same.

M_d is given by:

$$M_d = \frac{E}{e}$$

where e is the average emission factor ($kgCO_2$ per km) for a UK car and E is the total resultant emission of carbon dioxide per box for the large-scale system:

$$E = \sum_i E_i$$

with i running over all the sources considered (i.e. cooling, packing, administration, HGV, hub administration, hub cooling, LGV).

Table 20.3 Carbon emissions from the large-scale box system

Source, i	E_i, $kgCO_2$/box	% of total system emission
Packing, cold storage and administration at farm	0.30	21.4
HGV transport	0.36	25.7
Intermediate cold storage and administration at hub	0.04	2.8
Final LGV distribution	0.70	50.0

Table 20.3 shows the values found for E_i. The transportation of the product accounts for around 70% of the carbon emissions, and chilling at both the production/packing centre and the hubs account for about 30%. The single most important source is the LGVs used for final delivery; this indicates that efforts to reduce the environmental impacts of home delivery might best be focused towards this source in the first instance.

Using the results given in Table 20.3, and Eq. (20.1), M_d is found to be 6.7 km (4.2 miles), or 6.54 km (4.06 miles) if calculated in non-primary energy units, rather than carbon. This is a surprising result and arises from the inherent efficiencies of the mass distribution system outweighing other emissions.

The sum of associated CO_2 emissions for the large scale delivery system is 1394 g per delivery. A comparison with the perhaps more conventional route of individual customers driving to the theoretical farm shop can now be made. Department for transport statistics [TSGB 2007:Energy and the Environment Data tables, http://www.dft.gov.uk/pgr/statistics/datatablespublications/energyenvironment/tsgbchapter3energynvi1863.pdf>] provide the average CO_2 emission factor for cars on the road in the UK as 207 gCO_2/ km for petrol cars (equivalent to 31 mpg fuel consumption), and 188 gCO_2/km, 36 mpg in a diesel. Under the Government's labelling system this classes the average vehicle as an 'F' on a scale of A–G in terms of CO_2 emissions.

The headline figures used above relate to petrol vehicles due to the disproportionate use of petrol fuelled vehicles in relation to diesel.

Using Eq (20.1), M_d can now be found for the average petrol and diesel vehicles.

Petrol: $M_d = 1394\ gCO_2/207\ g/km$ $M_d = 6.7$ km or 4.2 miles

Diesel: $M_d = 1394\ gCO_2/188\ g/km$ $M_d = 7.4$ km or 4.6 miles

A similar calculation can be made in non-primary energy units by taking the calorific value of the vehicle fuel and making a comparison with the sum calorific value of the energy embedded in the distribution measured here (diesel, electricity, heating fuel) as shown in Table 20.4.

The sum energy expended throughout the distribution chain is 5.7 kWh per delivery, which equates to 0.6 L of petrol or 0.5 L of diesel. Taking the average

Table 20.4 Sources of Embedded Energy in Box System

Category	Energy per box (kWh)
Packing, refrigeration and admin at farm	0.64
HGV transport	2.14
Intermediate refrigeration	0.08
Final distribution (LGV)	2.87
Total	5.72

fuel consumption figures mentioned above we can then calculate M_d as 6.5 km/4.0 miles and 7.4 km/4.6 miles for petrol and diesel respectively. Thus for a consumer, the mass distribution system would be a more carbon and energy efficient way of obtaining vegetables if an extra trip of more than 7.4 km would have to be made to a farm shop.

20.2.3 Discussion on local food miles

The results of our study show that for the large-scale system the bulk of the emissions arise not from chilling or mass transportation using HGVs but the final delivery phase using LGVs. Whilst it is obvious that the box system results in many more food km (on average 360 km per box in this study) than purchasing from a local farm shop, this is shared between a large number of boxes. The need to consider this point when making use of the concept of food miles was one of the main conclusions of the AEA report (AEA Technology 2005). Our work shows that the concept of food miles, as typically used, is of little value per se and that it is the carbon emission per unit of produce over the transport chain that really matters. The concept of food miles has undoubtedly served an important ideological and political role in highlighting the importance of carbon footprints in the food system. To that extent it has been a useful device in the wider sustainability debate. But it is now time for businesses and consumers to adopt a more broadly conceptualized carbon accounting life cycle assessment. Riverford Organics, as one of the most well-known suppliers of organic produce, is playing a leading role in developing an appropriate methodology for this.

Sonnino and Marsden (2006) have argued that it is mistake to see 'alternative' and 'conventional' food networks as separate spheres. Instead there are a range of competing agri-food geographies built upon "different sets of quality and commercial conventions and different degrees of horizontal and vertical embeddedness' (Sonnino and Marsden, 2006). The food consumer is not confronted simply with a choice between 'local-good' and 'global-bad'. As our data above shows purchasing the most geographically local produce *per se* does not necessarily mean the lowest carbon impact. Many factors are involved. Nor is carbon the only way to evaluate the impact of purchasing

decisions. We might also need to factor in the implications for biodiversity and landscape, for local employment, for fair trade and for international social justice. The claims for the heuristic value of the concepts of food miles and of local food systems need to be seen in the context of careful evidence-based case studies of the type given in this chapter. At the same time we cannot expect consumers to take into account life cycle analysis of every product they buy, nor indeed that public or private sector bodies can afford to conduct such exercises for every product or retailing systems. What is needed is a sophisticated public debate on food systems in which catch phrases, such as 'food miles', which were useful to initially capture media attention, now give way to more nuanced approaches based on strategic case studies of specific retail systems and/or key commodity sectors.

20.3 Food miles and international food distribution

20.3.1 Background

The advent of mobile refrigeration allows the easy global transport of fresh produce without spoiling and so makes a broader selection of items available: from fresh Kenyan beans to New Zealand apples stored and shipped when the local season has ended. As shown in a recent Defra study on the public understanding of sustainable food, seasonality is now a concept lost on many consumers who have come to expect all produce to be available at any time of year regardless of the UK's climate (Defra, 2007).

Inevitably there is an environmental cost associated with the long distance sourcing of these items. Transport and refrigeration rely on fossil fuels to power them, resulting in the emission of various gasses which have a detrimental effect on the environment (Figure 20.3). Received (public) wisdom states that this impact varies approximately in direct proportion with the distance from source to consumer. The work discussed here shows that although this might be true for single mode transport of a product, this is rarely the case in the real world where many different modes are used in the supply chain.

Our work focuses solely on contributions to climate change measured in terms of the most important anthropogenic greenhouse gas-carbon dioxide (CO_2). It uses the database of purchases of the UK's largest vegetable box supplier to estimate the correlation between distance travelled by product to total carbon emissions from farm gate to box-packing warehouse.

Of the 18.9 million tonnes of CO_2 emissions generated as a result of food transport for the UK in 2006 (Defra, 2007) 47% were due to international transport of produce to the UK (see Figure 20.4). Clearly the CO_2 emissions associated with the international sourcing of produce are significant and

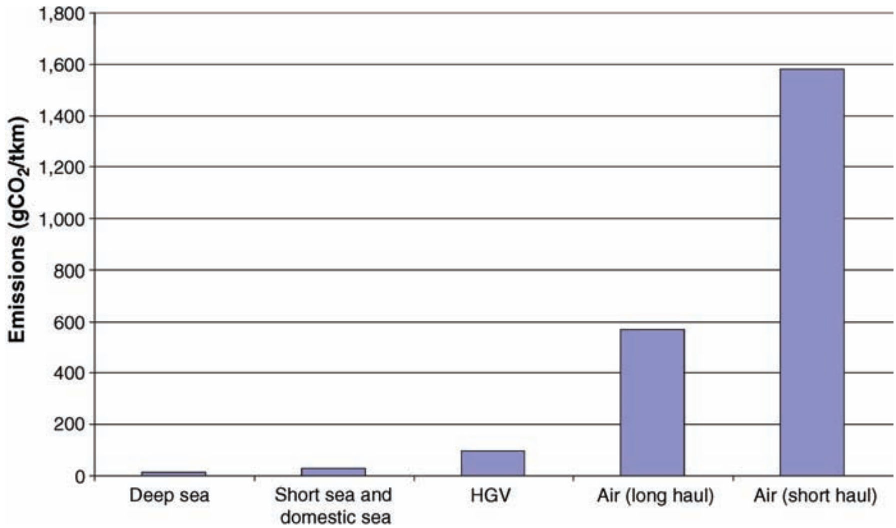

Figure 20.3 CO_2 emissions generated by different modes of freight transport.

therefore any sourcing policy should be based on sound principles, rather than *long distance bad, short distance good*, unless this can be proved to sensibly capture the essence of the problem and a reasonable correlation can be found between emissions and total transport from farm gate to consumer. In the following we measure this correlation for a large number of items and source countries using real data from a major supplier including the location of farms and accounting for transport and storage emissions in the county where the produce is grown.

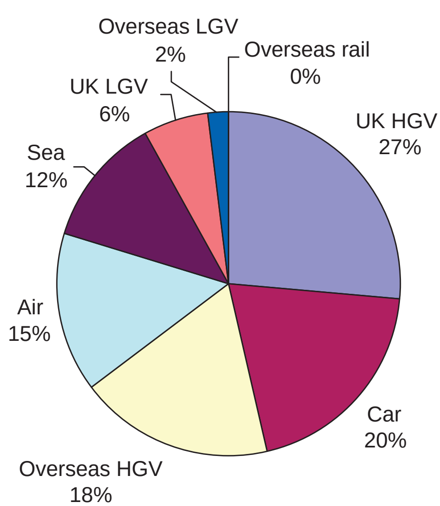

Figure 20.4 Mode and location for UK food transport.

Previous work has questioned the concept of 'food miles' (AEAT, 2005; Coley, Howard and Winter, 2009). The results of our work show similarly that, for mixed mode international transport, this questioning is valid for a wide range of produce and locations.

20.3.2 Method

There are essentially three variables that drive CO_2 emissions from freight, these are the distance travelled, the mass transported and the mode used. Emission factors derived as part of Defra funded research have been used in this study, they are given as gCO_2 emitted per tonne-kilometre for a given mode. A tonne-kilometre being a measure of both mass of produce, and the distance the food has been transported. Details of the derivation of these factors can be found in AEAT, 2005, but in essence we have:

$$E_{\text{source}} = \sum_{\text{mode}} EF_{\text{mode}} X_{\text{mode}} \tag{20.1}$$

where EF_{mode} signifies the CO_2 emissions factor (in gCO_2/tkm) for a given mode of transport, X_{mode} signifies the distance travelled by the individual mode of transport and E_{source} signifies the CO_2 source and transport mode weighted emissions for the particular source (or farm) in question in terms of gCO_2/kg produce. Typically Equation (20.1) can be written as:

$$\begin{aligned} E_{\text{source}} = {} & \left(EF_{\text{deepsea}} \times X_{\text{deepsea}}\right) + (EF_{\text{shortsea}} \times X_{\text{shortsea}}) + (EF_{\text{HGV}} \times X_{\text{HGV}}) \\ & + (EF_{\text{air}} \times X_{\text{air}}) + (EF_{\text{LGV}} \times X_{\text{LGV}}). \end{aligned} \tag{20.2}$$

The great difference (a factor of 40–100) between the emission factors for air transport and shipping (Figure 20.4) has led many to sensibly conclude that air transport should be avoided. What has been given less public exposure is that shipping has a much lower emission factor than HGV-based transport (by a factor of 6.4 for deep sea and 1.9 for short sea). This leads to the possibility that sourcing from more distant locations that allow the use of water-borne transport might result in lower carbon emissions than sourcing from farms more closely located to the retailer.

The retailer's database of purchases for 2006 was used to estimate the carbon emissions from the regular sourcing of items from 56 locations in 26 different countries. Routes were mapped from the farm gate to the whole-seller, then to the packing house in the UK and broken down into distance travelled by each transport mode and Equations (20.1) and (20.2) applied. From this, CO_2 emissions generated by importing a kg of fruits or vegetables by that route were calculated. The results are presented in Figure 20.5.

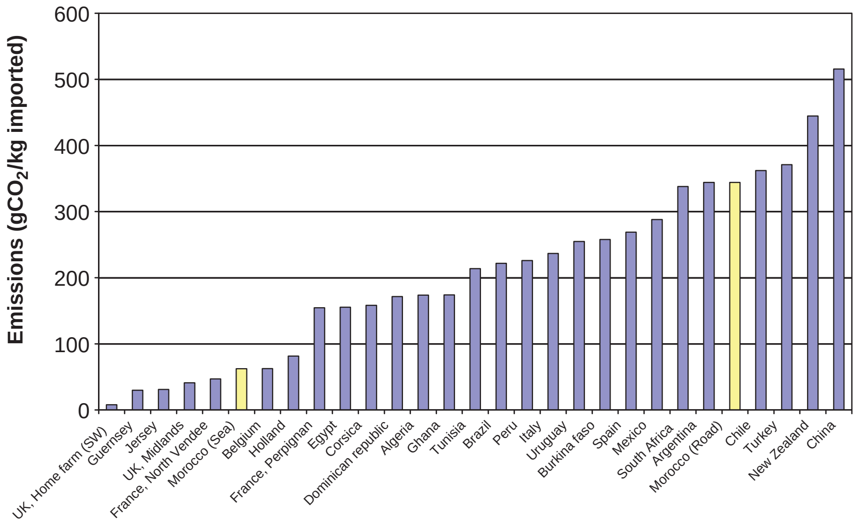

Figure 20.5 A selection (for clarity) of source and mode-weighted emissions (gCO_2/kg imported) estimated for a single farm in each of the 26 countries studied. (Note although the locations are identified by country, they are specific to the farm and supplier used by the retailer in each country and they should not necessarily be seen as representative of the whole country.)

For sea transport, emission factors were based on the Defra Guidelines for Company Reporting on Greenhouse Gas Emissions, supplemented by other sources. The Defra guidelines were specifically aimed at companies wishing to assess their CO_2 emissions and give an estimate of CO_2 emissions per tonne of freight for several different ship types: small and large ro-ro, liquid bulk and dry bulk. However, container ships, which were not included in the Defra guidelines, also carry a high proportion of food freight. AEAT derived emission factors for these container ships based on the average of a ro-ro and a bulk transport ship (AEAT, 2005) and then made assumptions for the percentage of food freight carried by each type of ship, for both short sea and deep sea transport, and used these to derive weighted emission factors for short sea and deep sea freight.

The mix of ship types was derived from an analysis on what fractions of imported and exported foodstuff are dry bulk (i.e. cereals, oil seeds, animal feed and waste) both in Europe and the rest of the world (based on HM Customs and Excise statistics). It was assumed by AEAT that all dry bulk was carried by dry bulk ships. For short sea transport they assumed that one third travelled in large dry bulk ships and two thirds in small ships. For deep sea transport they assumed 75% in large and 25% in small ships. Of the remainder, it was assumed that for short sea transport, 75% travelled by ro-ro and 25% by container, with half in large ships and half in small ships. A summary of the emission factors used is given in Table 20.5.

Table 20.5 Emission factors used in the study

Transport mode	Emission factor (gCO_2/tkm)
Deep sea	0.015335
Short sea	0.029381
HGV	98.15

The following additional assumptions were made:

- Transport emissions are based on pre-determined routes of import combining HGV and shipping.
- Distances include the distance from farm or collective to shipping point and from the point of arrival in the UK to the retailer's distribution and packing centre.
- Road distances are taken from Microsoft mapping software Live Local.
- Shipping distances are taken from www.shippingdistances.com.

Interesting results are seen for some countries such as Morocco (highlighted in Figure 20.5) which can appear at the higher end of the scale despite being relatively close to the UK if the produce is mainly shipped over land (through Spain), or at the lower end if shipped by sea. In general, because of the higher CO_2 intensity of road freight in comparison to sea, it was found that sourcing from regions closest to shipping ports (thus minimizing road transport) would result in the lowest emissions.

20.3.3 Regression analysis

Scatter plots of the emissions resultant form sourcing items from the individual farms were plotted against the distance the produce travelled and linear regression applied (Figure 20.6). The results might be considered surprising. As Figure 20.6. shows, there is little correlation between the distance the produce travels and the resultant emissions and this is confirmed by estimation of the correlation coefficient ($R^2 = 0.3$). Clearly there are two relatively independent, well-correlated, populations within the data and, as Figure 20.7 shows, these correspond to situations where the majority of the distance travelled is by sea, or by road. (The retail company considered does not import via air.)

20.3.4 Influencing purchasing decisions

Having shown that: (a) the concept of food miles is a poorer than expected environmental metric for this sector, and that (b) calculating carbon emissions over the mixed mode cycle with account being made for differences in tonnage

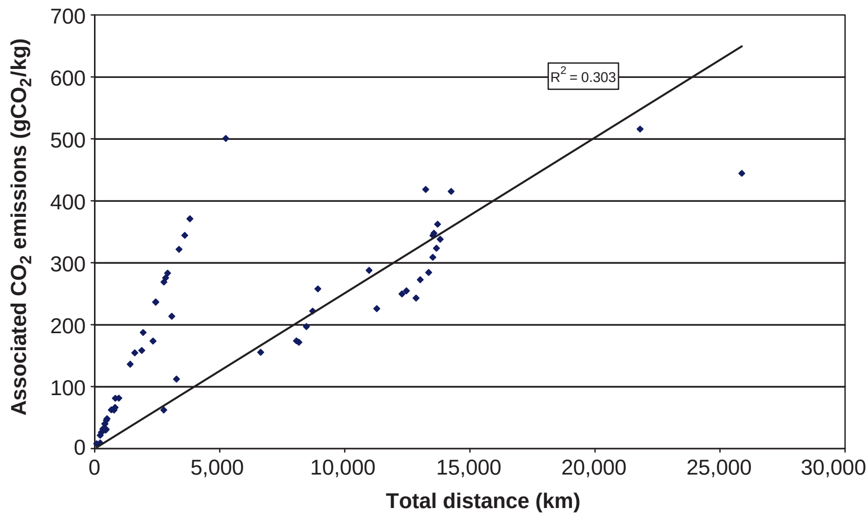

Figure 20.6 Scatter plot of distance vs. CO_2 emissions for international sourcing routes (and all 55 farms in the study), note the low R2 value, indicating a poor correlation.

transported by the ships and trucks involved was achievable within the database systems of a large retailer, two attempts were made to influence purchasing behaviour, one at the level of the customer, the other at the moment of bulk purchase by the retailer.

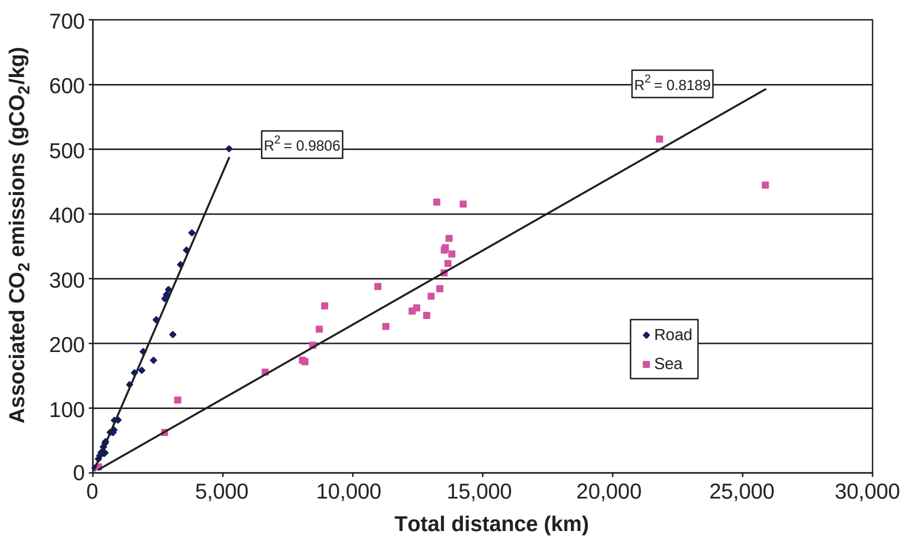

Figure 20.7 Scatter plot of distance vs. CO_2 separated into routes relying predominantly on road transport and those relying predominantly on sea.

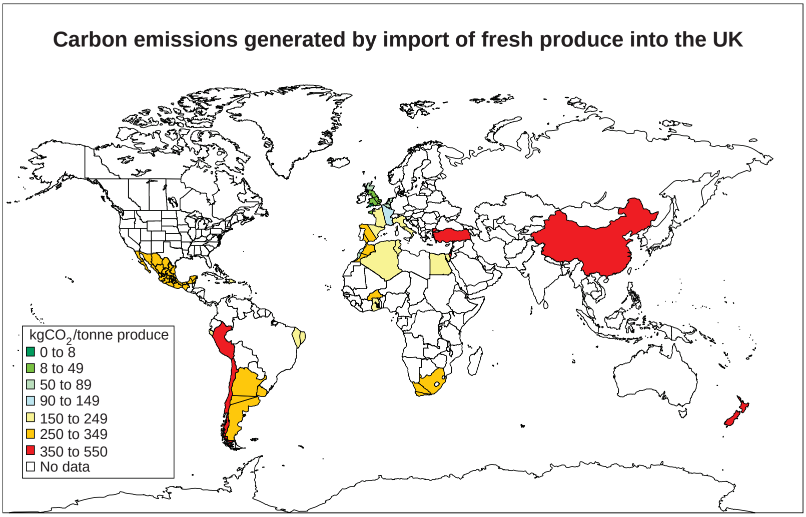

Figure 20.8 Visual representation of the CO_2 emissions associated with the import of fresh produce into the UK, some source countries have been separated into regions to represent different locations within the country itself.

To achieve this, three tools and representations were developed. The first was purely pedagogical – a map of the world coloured to reflect the mixed-mode emission factor for each location that the retailer uses (Figure 20.8) and used to ensure bulk buyers and customers understood the issue. In essence, this contains the same information as Figures 20.6 and 20.7, but presented in a more usable way: one can clearly see that distance is not the sole driver in the resultant emissions. For example, note the lower emission factor for parts of the USA than the Eastern Mediterranean.

In addition to the representation shown in Figure 20.8, a spreadsheet was developed that applied the farm-specific mode-weighted emission factors to the contents of each week's eight vegetable box types (the retailer distributes 1.5 million boxes per annum) and presented the results to bulk purchasers within the retail company. This allowed them to examine the impact of alternative sourcing on the carbon footprint of the different vegetable box types assembled each week. Purchasers could then make sourcing decisions based on keeping the footprint of certain boxes below certain limits. This could be done by either choosing to source the same product from a location with lower resultant emissions, or to make a substitution for a different product.

The final step was to allow customers access to the estimated carbon footprint of each box each week before purchase. They could then elect to receive whichever of the eight boxes most closely matched their desire for specific contents and level of carbon emissions.

20.4 Conclusion

We commenced this chapter by carrying out a comparison between the carbon emissions resultant from operating a large-scale vegetable box system and those from a supply system where the customer travels to a local farm shop. Growing and sourcing of produce have not been considered in the comparison, as both typically operate in a similar way in regard to this in the UK. The study was based on fuel and energy use data collected from one of the UK's largest suppliers of organic produce.

We have found that if a customer drives a round-trip distance of more than 7.4 km in order to purchase their organic vegetables, their carbon emissions are likely to be greater than the emissions from the system of cold storage, packing, transport to a regional hub and final transport to customer's doorstep used by large-scale vegetable box suppliers. This suggests that with regard to such emissions, some of the ideas behind localism in the food sector may need to be revisited. But such a conclusion needs to be seen in the broader context of sustainability, as indicated in the introduction to the chapter.

We then used data from a large UK vegetable box supplier to estimate the correlation between food miles and carbon emissions resulting from the international sourcing of produce. The correlation was found to be very poor and it is clear that the mode of transport is as important as the distance, with sourcing from parts of the Mediterranean resulting in emissions greater than those from the Americas. This result led to the development of tools based on farm-specific mode-weighted emission factors that take account of the mass of product carried by each mode and the fuel efficiency of each mode. These tools have since been used in an ongoing attempt to influence purchasing behaviour.

This chapter led with the suggestion that the agro-food sustainability debate has been narrowed and limited by the recent public and policy focus on food miles and carbon emissions. And yet the empirical material included in this chapter is devoted mainly to an examination of food miles and carbon emissions. Our justification for this is simple; we have sought to engage with the debate on its own terms and in so doing have highlighted the weakness of relying on a single simplistic emblem of sustainability – food miles. We do not, of course, suggest that carbon emissions are anything other than a vital factor in the sustainability debate but we would argue that a wider approach to sustainability is, perhaps paradoxically, more likely to give rise to coherent thinking around carbon emissions than the reduction of the issue to the totemic one of food miles. In particular, the inclusion of economic and social dynamics in any promotion of sustainability is vital, such as the engagement of consumers in thinking through the consequences of their purchasing decisions. We would argue that food miles, and indeed a number of other beguilingly simple ideas for climate change mitigation such as carbon offsetting, have two major drawbacks. First, as shown empirically in this chapter,

they can be misleading in terms of real world processes. Secondly, they can divert attention from the far more fundamental and deep rooted social, economic and environmental changes that are required to tackle the sustainability challenge.

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21
Sustainable Global Food Supply Networks

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21.1 Introduction

Recent trends towards global trading and the formation of global scale supply networks make the task of supply chain management more and more challenging and have significantly increased competitive pressure. Not only do organizations have to constantly evolve and develop new strategies to meet the needs of their customers, they must also develop parallel strategies to outperform their competitors. This global scale drive within the organization means that competitors are no longer confined to a local environment as the trend to seek global trading partners and develop global trading networks is the norm as opposed to the exception in an attempt to achieve cost efficiencies. Organizations are constantly evolving from functioning on a local scale – serving its local community to a more international focus whereby they are no longer restricted by physical distances and time zone barriers. This demand places significant burden on existing business processes and requires a significant shift in the strategy of organizations.

Many organizations have mastered the management of their information on a local scale relating to their own in house processes. The ability to create information sharing channels functioning in parallel with the flow of product are just some of the challenges facing organizations in the management of their

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supply chains and networks as opposed to simple internal house record management systems. These in house systems are isolated in functionality and may all too often be disjointed, inaccurate and incompatible with other systems, and lack all the characteristics required for the development of Sustainable Supply Networks. One of the key requirements of a sustainable organization is the ability to make all processes within the organizations and all its trading partners transparent as is recommended in the global reporting initiative (Labuschagne et al., 2005).

We must aim towards the attainment of sustainable food supply networks using innovative technologies in an organizational learning environment, through innovative value adding technologies that will improve the quality of our lives at no cost to the environment or to food security. Although many organizations may hold a somewhat sceptical view of sustainability it should be highlighted that there is a positive correlation existing between sustainable development and economic performance. Organizations can no longer base decisions solely on financial merit. Modern day organizations must incorporate the triple bottom line into their decision making process to implement the architectural framework of a sustainable future development.

21.2 What is sustainability

Sustainability development is defined as development that meets the need of the present without compromising the ability of future generations to meet their own needs Seuring and Müller (2008). In terms of strategy within the business environment sustainability aims to create long-term shareholder value by embracing the opportunities and managing the risks that result from an organization's economic, environmental and social responsibilities (Pojasek, 2007). The days when an organization's responsibilities lay solely on its shareholders and their dividend return are gone. Currently many board of directors find themselves in positions where they must do more than simply meet financial targets, they must now consider a broad group of stakeholders. Organizations are required to embrace a level of corporate social responsibility (CSR) in an attempt to incorporate and sustain a sustainable organization (Labuschagne et al., 2005). To operate on a sustainable level the organization must adopt a resource based view in order to successfully implement the concept of the TBL and also include enterprise systems and governance chains. This area of corporate governance and CSR is all too often treated with an attitude of laissez-faire and in some cases enlightened self-interest, much to the destruction of the organization and all concerned. Opposing this, the need to please being placed on many organizations is very often too difficult, due to the fact that trying to reconcile the interest of all stakeholders at any given time can prove to be timely and often impossible. Some of the common stakeholders include local communities, financial institutions, suppliers, customers,

competitors, shareholders, management, governments, employees and pressure groups.

Many organizations these days think of sustainability in relation to operations and production as just encompassing 'waste management'. This is a very limited interpretation as sustainability should be thought of in terms of innovation and its potential to lead to operational efficiencies. In other words a proactive and open minded approach in a learning environment is the desired approach towards sustainable development as opposed to a reactive approach. For an organization to be classified as a learning organization it must focus on knowledge acquisition, development and diffusion from a variety of organizational sources including people, systems, culture, routines, procedures and processes. The learning organization must then interpret and diffuse this knowledge throughout the organization by means outlined later (Kelly, 2009). Organizations can no longer base decisions solely on financial merit, modern day organizations must incorporate the triple bottom line into their decision-making process to gain stakeholder acceptance. Becoming a learner organization is an essential part of adopting a strategy of sustainability within an organization (Kelly, 2009).

21.3 Sustainability strategic development

Over the last number of years, organizations have increased their boundaries and networks by evolving from their traditional approach of functioning locally for the community to a more international focus spanning across international boundaries and time zones. To do this they have had to dramatically restructure and develop new strategies on which to meet expansion demands. By loose definition an organizational strategy is defined as encompassing the long term direction and scope of an organization with the aim of achieving an advantage over competitors via the organization and/or reorganization of resources, to meet the needs of markets and to fulfil stakeholder expectations.

A culture of sustainability is not necessarily organically grown within organizations and it is often a concept that will require investment to meet basic requirements. The main key drivers of sustainability and sustainable frameworks are the organizational stakeholders. Over the past years environmental and ethical issues have made their way into the area of supply chain management and the overall business strategy. To successfully adopt these strategies, organizations will also have to adopt a learning approach to strategic development. It is obvious that there is a direct link between an organization's attitude to sustainability and its impact on its immediate surrounds and on a larger scale its entire supply network. It is for this reason that an organization's attitude towards adopting a *triple bottom line* decision architecture is key to its sustainable development. A major requirement in the drive for sustainability is to create full transparency in global supply networks.

As well as benefiting the consumer transparency in the supply networks may also be of benefit to the organization themselves facilitating real time visibility which offers more accurate logistical operations leading to lower economic losses due to lost or delayed product. It also provides the management with a tool which they may use to analyse the full supply chain and help highlight any weakness or areas requiring attention. Management also conduct an internal evaluation of their full supply network with a view of highlighting value adding processes.

As previously mentioned a core element of a strategy for sustainability is the incorporation of the Triple Bottom Line. This sets out that an organization's license to operate in society does not only come from financially satisfying customers (financial bottom line) it must attempt to satisfy the needs of the environment (planet) and also meet its social requirements (People) (Kelly, 2009).

There are a number of key drivers for sustainability within the modern day organization, the main ones being the consumer and also the economic drivers in terms of process restructuring. The modern day consumer is much more demanding than ever before and they wish to know product facts such as the source and quality of the product. They also wish to know if the product has in any way been altered either chemically or physically or if it contains any additives or preservatives or genetic modification. Another product attribute that seems to be gaining popularity is the carbon footprint of the product as a number of studies have shown that factors such as these are influencing the decision-making process of the consumer. Moreover the aforementioned economic drivers are also being significantly affected by these consumer drivers as organizations must give in to 'buyer power' in an attempt to give in to or achieve market leadership in their particular field. As with all new business processes sustainability does not come for free and traditionally organizations may pass this extra cost on to the consumer, yet in the majority of cases the capital required must be self sourced which has often been a barrier to adoption and as a result share yields/dividends may drop. This, however must be offset against the buyer power of the consumer and their demands which may include the availability of ethically sourced and/or organically produced healthy products.

Organizations spend a lot of time trying to attain the correct balance between meeting consumer needs, operational targets and reducing the environmental impact of the organization via the TBL business approach. Major TBL stakeholders' principles are national governments and environmental groups around the world where governments have the ability to legally force operational protocols and the environmental groups establish influence through public support via both positive and negative marketing campaigns.

To adopt a successful strategy for sustainability an organization must have in place a collective systematic methodology for measuring sustainability in terms of all business processes including procurement, logistics, production

and after sales care. The organization must take the responsibility of ensuring their raw materials are sourced and disposed of ethically where possible. The organization can no longer distance itself from trading partners as they must ensure their partners adopt a similar level of ethical responsibility as they themselves adhere to, and more importantly, they need to make this information transparent. Again in cases where organizations adopt these strategies, they often find opportunity to leverage their marketing strategies and gain consumer confidence.

Organizations functioning across geographical boundaries struggle to strike a balance between all the factors with relation to their global supply network. This global network aims at establishing value creating activities by placing numerous activities in a variety of geographical locations at different stages of production in order to maximize value adding potential and gain cost strategy leverage. This global network aims at establishing value creating activities by placing numerous activities in a variety of geographical locations at different stages of production in order to maximize value adding potential and gain cost strategy leverage. This has resulted in some organization receiving negative publicity after relocating certain aspects of their business, for the purpose of financial gain, to geographical locations where labour laws and ethical regard often come under the questioning eye of the public.

Another important component of sustainable organizational development is information. Within the organization, strategists use this information to evaluate a particular process, to see if it is meeting targets and to convert it into knowledge with which future projections and strategies may be based. Organizational information has helped shift the value focus within the organization from tangible assets (buildings and machinery etc.) to intangible. The major challenge is to be able to gather, store, manipulate and distribute this information within the organization in real time. The ability to gather this information facilitates transparency which is key to the realization of a sustainable organization. There have been a number of technologies proposed to facilitate supply chain traceability over the last number of years, which all have varying degrees of success. There is also no one single technology that can achieve this. Among the most promising technologies to facilitate supply chain transparency are Radio Frequency Identification (RFID), Biometrics and Data management technologies, which will be the focus of the following section.

21.4 A technological approach to sustainable global supply networks

In monetary value the global import and export market was worth 15 174 439 million USD in 2010, up from 2 035 542 in 1980. A major contributing factor towards this significant increase is due to correct supply chain management

practices and modern day information communication technologies (ICT). Combined, they have the ability to help organizations overcome any issues in terms of distance, time and or language barriers. Each organization relies on products (or raw material) being delivered on which they add value (via a process) and transform it into a product which they then sell to the consumer or another processor.

Global supply chains function from within every organization and the key to their success is the communication flow between trading partners. Accompanying the difficult task of physically moving, handling and shipping a product across the globe in a timely fashion is the other equally complex and challenging task of information flow. This flow of communication is vital for both upstream and downstream trading partners as it can inform the buyer about the location and state of a particular product at any stage during transport.

In a conventional traceability system one of the major challenges to implementation is to ensure that the information passed between trading partners along the supply chain must be accurate, reliable, timely, consistent, transferable and relevant for it to be truly useful. This task is made all the more challenging when each party involved has different requirements for this information in terms of informational content, which may be due to the fact that different trading partners may be bound by law to store and record different pieces of information for specific items (Morreal et al., 2011). It has been shown that there are two elements of the supply chain requiring attention when being viewed from a sustainable perspective. The horizontal dimension concerns requirements and legislation that apply to each specific organization along the supply chain. It relates to concerns from stakeholders and consumers and may be viewed as being particular to each organization. The vertical dimension on the other hand relates to common legislation to all companies within a particular network (Wognum et al., 2011).

As it has now been highlighted, over recent years, global supply networks have expanded to span across time zones and across national and international markets. This requires a high level of details in terms of strategic development to factor sourcing, logistics, processing, storage and distribution across multiple locations. For a global supply network to be sustainable it must develop and implement a strategy that will enable the facilitation of all organizational tangible assets, such as buildings and employees, and merge it with the internal intangible assets, such as rules, policies, culture and knowledge. All this information must be made available to the organization in real time on demand. There have been a number of technologies proposed to help facilitate supply network visibility (Mc Carthy et al., 2012). This section will highlight three technologies which the authors feel will add value to global supply network sustainability by facilitating real time visibility and transparency across the full network.

21.4.1 RFID

Radio Frequency Identification (RFID) is now more than ever being incorporated into business processes due to its ability to identify and locate, in real-time any object to which a tag is attached (Mc Carthy et al., 2009). A major technological competency is its ability to wirelessly transfer data in real time offering the advantage of not being dependent on an established line of sight for communication (coupling) (Chen and Thomas, 2001).

RFID technology also offers the ability to accommodate user defined data on each individual tag memory which may be updated and interrogated (read) at any point during production or transport facilitating item level traceability along the supply chain, providing both asset and process transparency. RFID offers varying levels of security, whereby encryption of the user defined data is possible as well as the user ability to create personal password locks on tags to restrict access (Wonnemann and Struker, 2008) (Kobayashi et al., 2007). It is classified as an Automatic Identification Data Capture (AIDC) technology which also contains biometrics, smart cards and voice recognition (Hansen and Gillert, 2008). It is viewed by many as being a suitable replacement and logical evolutionary development from the common bar code and offers an ideal, real time data carrying technology that, in combination, provides the ability to increase the integrity of the entire supply network.

At its most basic and RFID system contains three core components. A transponder (tag) is attached to the asset that is to be tracked and identified. These tags come in an assortment of shapes and sizes, possess diverse functional capabilities, and as a result can be applied to a variety of applications in each case the selection criteria is based on the desired application. Secondly, transceivers (readers) which again come in a variety of shapes and sizes and are attached to a PC which, by use of a reader, facilitates interaction with the user of the technology and allows user control of the system. Finally, attached to the reader are antennas which facilitate the wireless link between tag and reader and are the core component of communication between tag and reader. There may be a single or multiple antenna attached to the reader at any one time. They are responsible for the propagation of an electromagnetic wave into the surrounding environment which acts as an information carrying medium on which the wireless data transfer link operates.

It is now clear that radio waves are an essential component of RFID system functioning, and with this in mind, it should be highlighted that radio waves are contained within the electromagnetic spectrum ranging approximately from 3 KHz to 300 GHz. With this large frequency span comes a huge variation in RF characteristics which in turn afford RFID technology the versatility that has enabled it to be incorporated into a large number of industry sectors. Ultra High Frequencies (UHF), 300 MHz to 3 GHz which include the popular Class 1 Generation 2 UHF Protocol (EPCglobal, 2008), host most of today's RFID applications. Due to its high level of automation, RFID technology has

become commonplace in applications such as supply chain management, product life cycle management, asset management and warehouse management systems and numerous similar applications where assets are tracked in real time (Tajima, 2007) (Hossain and Prybutok, 2008).

The wireless link between an RFID tag and reader can provide different kinds of data and information transfer not necessarily limited to tag and reader identifiers like unique tag labels created using the EPC C1G2 standard. In fact, some of today's RFID applications aim to improve the business efficiency and profitability by increasing transparency with wireless technologies that can monitor and report environmental conditions, such as temperature and humidity across the entire supply chain (Opasjumruskit et al., 2006). In case of heat sensitive products such as perishable foods or biologics, RFID sensor technology can not only provide a higher level of supply chain integrity, but can also reduce waste and increase customer satisfaction with improved product quality. While RFID pilots on perishable foods go back to 2003, it was only recently that the impact of using RFID on biologics, such as blood and blood components as well as biopharmaceuticals has been shown to have no effect by different research groups (Uysal et al., 2012). An RFID sensor tag constitutes of a sensory circuit and an RFID chip capable of wireless RF communications. Depending on whether the RFID chip is powered by a battery or not, they are categorized into active and semi-passive tags respectively. The information, such as recorded temperature history, is communicated wirelessly to the RFID reader and later to a computer host/database for further processing.

It is important for the reader to know that there are different tiers of benefits provided by using an RFID enabled sensor system. An immediate perk is the detection of abnormalities in the supply chain, such as when a pallet is subjected to temperature abuse or there is refrigeration equipment failure during transportation or storage. However, the true value of such an application becomes more evident as the sensory data, like temperature, is processed into second tier information such as quality or shelf life of a product. Using shelf life estimation algorithms, a user can not only tell the temperature history of a product, but also its quality and remaining shelf life at various points along the supply chain on-demand. Accessing this type of information enables trade partners to enhance quality control decision making and more quickly resolve disputes. Finally, there is a third tier of benefit which goes beyond shelf life and quality by utilizing that knowledge to make smart decisions on the optimization of the supply chain itself. For instance, with on-demand access to quality and shelf life of perishable products in a warehouse, instead of using traditional distribution techniques such as first-in-first-out or as commonly called FIFO, one can use first-expired-first-out or as commonly called FEFO, to manage their perishable inventory. Hence, data-to-information-to-decision reduces waste and improves overall sustainability of the perishable supply chain.

Other successful incorporations outside the UHF spectrum include animal identification technologies (Kampers et al., 1999). Examples include Low Frequency (LF) RFID bolus injected into the rumen of the animal to remain there throughout its life time and has proven to be a successful tamper proof method of automatic identification. More recent work embedded High Frequency (HF) RFID tags in the ear tag of the animal and again, RFID technology proved to be a far more robust technology compared to bar codes in ear tagging applications (EuropeanComission, 2005). They are also commonly used in retail outlets and anti-thief devices. Over recent years RFID technology has been successfully incorporated into a wide variety of industries including: pharmaceutical industry, building access control, toll collection, vehicle immobilisation systems, aviation industries, waste management and mining industries (Chao et al., 2007) (Ngai et al., 2008) (Roberts, 2006).

With an opening of global markets and mounting pressures being placed on organizations to operate on a global scale to improve efficiencies, the business case for RFID technology should not be overlooked. It has the ability to form an integral part of all organizations' enterprise systems which will aid in all aspects of supply chain management including purchasing, manufacturing and distribution. Due to its fully automated electronic properties RFID offers advantages never before achievable with previous technologies. From a strategic managerial perspective, RFID technology can provide an electronic automated platform on which expanding organizations can monitor and record all transactions and it also has the ability to report on market trends through customer relationship management (CRM). From an operations perspective UHF RFID technology can lead to a reduction in inventory waste, higher inventory control, more efficient logistical approach and a reduction in labour costs. All of these advantages again facilitate modern day organizational expansion.

RFID has demonstrated the ability to track and trace items down to item level in a fully automated fashion with relative ease of integration into ERP systems and had the added advantage of transport conditions monitoring during transit. This makes it a very powerful supply chain management tool and in conjunction with its scale potential when accompanied with the EPC network makes it an essential component of modern day organizations. Of major importance to the success of RFID and the EPC network are the individual reasons for implementation. WalMart mandated its suppliers to use RFID on all products supplied to it which faced a huge burden on these suppliers and implementation in a time when the benefits of the technology was not fully understood. It has been shown that not all areas of the supply chain share the cost of implementation equally (Mo et al., 2009), in many cases, full cost of the implementation is passed onto the suppliers. For this reason, successful implementation will only come about with an understanding of the technology and not just a slap and ship approach, which was forced onto

a number of organizations as a result of the mandate and turned out to be an unwanted expense.

While it is relatively simple to calculate the cost of implementing an RFID system within an organization its true ROI is a lot more difficult to calculate (Attaran, 2007). It is important to note that information may be a burden (storage costs, etc) on an organization or it may prove to be imperative in the development of a sustainable competitive advantage provided it is interpreted and used correctly. As a result, the cost of implementation is relative to the ability to use this information, which suggests that ROI is specific to each organization from an operational perspective.

21.4.2 Biometrics

It is now clear that supply chain transparency is a key component of sustainability. The food industry is no exception to this and over the last number of years an all too common weakness in the *farm to fork* chain of custody has been at farm level. Traditionally this has been a source of difficulty in implementing a secure and transparent method of animal identification that functions in real time and offers a superior level of transparency. All too often at farm level information may be mishandled and reported incorrectly which may lead to a breach in system integrity in times of crises and consequently an inevitable loss in consumer confidence. Over the last number of years extensive research has been carried out on the use of biometric identification in the food supply chain. The fact that the biometric analysis confirms recognition based on unique individual physiological characteristics make the technology virtually tamper proof to date (Gonzales Barron et al., 2008). A biometric identifier particular to the individual animal is stored on a secure database and may be retrieved for future on site, real time identity verification (Golden et al., 2004). In the case of animal identification, biometrics is ideal as it remains with the animal throughout the course of its farm life. These biometric identifiers are unique to the animal and are tamper proof (Figure 21.1).

There are a number of different technologies being used and tested today as outlined below.

21.4.2.1 Facial recognition technology This is a non-intrusive and inexpensive biometric that may be obtained from still images, video sequence and/or thermal imaging. This technology is based on the location and shape of facial attributes such as eyes, eyebrows, nose, lips and chin and their spatial relationship; or secondly the overall analysis of the facial image, using either a holistic or subspace method (Delac and Grgic, 2004). Previous findings have revealed a 96% recognition success rate yet further work is required on the technology before being incorporated as a commercial identity verification technology (Corkery et al., 2007).

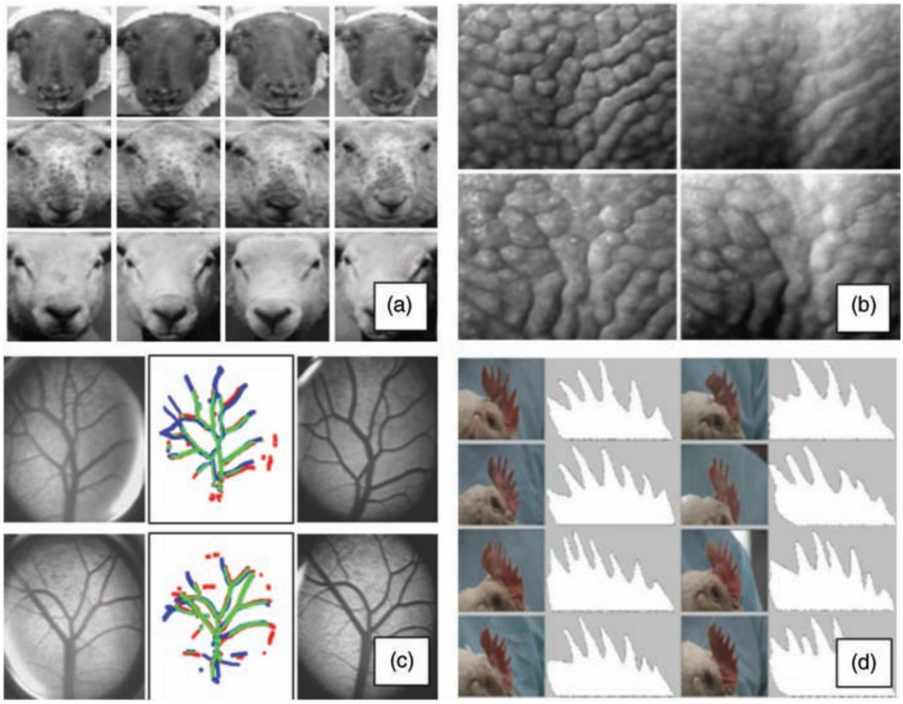

Figure 21.1 Illustration of biometric traceability systems for animals and poultry: a) facial recognition of sheep, b) muzzle identification of cattle, c) retina identification of sheep and d) comb identification of poultry. (Photos courtesy of Dr Gerard Corkery).

21.4.2.2 Muzzle pattern technology This technology exploits the muzzle pattern of bovine animals. Similar to a fingerprint a muzzle pattern is a dermatoglyphic trait unique to each animal. Specific coding has been developed to identify bovine animals through their unique muzzle pattern by analysis of the beads and ridges. Muzzle beads are structures spread all over the muzzle which may be oval, rounded or irregular in shape. Ridges have been described as elongated straight or curved structures arranged in a unique manner. Analysis of the data was carried out by one or two of the following methods, from directly lifted ink prints from the animal's muzzle; or from, digital images obtained from video sequence. This method proved challenging due to difficulty in obtaining a clear ink print from the muzzle. A successful recognition rate of 98.8% was obtained (Barry et al., 2007).

21.4.2.3 Retinal recognition technology This operates by capturing a near-infrared ocular digital image of the retinal vascular pattern of livestock. The technology has been specifically developed for livestock identity by Optibrand^{TM}. Once captured the vascular pattern is stored on a secure database as

a new animal (entry) and it is compared to previously stored (entries) vascular patterns for identification verification purposes. Retinal vascular patterns have proven to be a highly unique characteristic as the probability of two similar patterns occurring is virtually zero (Whittier et al., 2003). A study revealed that even monozygotic twins do not possess the same retinal vascular pattern. Other advantages of this technology include its low cost, high accuracy and its ability to function outside the laboratory (Allen et al., 2008). It is also tamper proof and the animal's unique vascular pattern remains unchanged throughout the development of a normal eye. During the animal's lifetime (Barry et al., 2008) obtained successful identification rates of up to 96 % using retinal vascular pattern imaging in lambs.

21.4.2.4 Comb biometrics (poultry) The avian comb of broiler chickens has shown potential to be a secure biometric marker (Corkery et al., 2009). The research consisted of video capturing comb profiles. Morphological image processing techniques were performed on still images obtained from the videos. The matching of the comb profiles of the hens was carried out using a Fourier-based technique for shape analysis. The results were statistically assessed and demonstrated a positive classification rate of up to 84.4%.

21.4.3 Data management systems

Hundreds of thousands of transactions take place within organizations each year. A transaction is any action or process necessary to carry out business and includes purchasing, ordering payroll and billing. Most organizations have now automated these processes and store them on a centralized database via the integration of enterprise systems.

Enterprise systems integrate all the information regarding each system processes within an organization to accommodate information transfer between each process. They attempt to join any information silos that may have been formed between functional departments such as HR, finance, operations thus preventing isolated databases and fractured information flow. They are often formed through the creation of synergies of a number of systems within the organization. An organization with such a system has the advantage of being able to link (compare and contrast) each different process within the organization and provides the ability to make strategic decisions both on a local and international scale in real time, thus improving market adaptability. Some of the many reasons why a company might opt for an enterprise system include harmonization of processes within the organization, inventory and logistical control and visibility, synchronization of information and product flow, integration of existing legacy systems, facilitation of global expansion through standardized data transfer, productivity refinement, and enabled collaboration with supply chain trading partners.

Information communication technology (ICT) is an area essential to all business processes. It has gained considerable acceptance and scale potential with the growing popularity of the internet. It has formed the backbone of the ability of organizations to trade and function globally. These are some of the properties that make ICT a pivotal technology in an organization's ability to achieve global scale sustainable supply networks. It is an essential communication medium for organization, both internally and externally. Organizations no longer rely on postal services or hand written transaction – the push is now for electronic versions. Information gathered from each source must be centralized in order to facilitate gathering, analysis, interpretation and redistribution via a number of channels to make strategic decisions which give companies the ability to create and sustain a competitive advantage in modern day organizations. Within the organization information is an intangible (soft) asset coming in the form of knowledge assets (employee knowledge), collaboration assets (value chain interaction), engagement assets (motivation of employees), and finally time as an asset (how quick something is achieved). Correct ICT system has the ability to manage and distribute all these assets throughout the organization.

To understand these systems and their role within the organization it is important to know where information is sourced from within the organization. It has been generally accepted that there are a number of main information resources within an organization including:

Data this is sourced from within the organization and is represented as raw untreated data which may be attained from sources including: production, HR, marketing, logistics (both inbound and outbound) and finance. Data is not edited or refined and not useful to many in its original format. Data may be structured which implies it has a certain level of arrangement including the way in which it is stored (via a database), or secondly it may be unstructured which includes a collection of different formats such as audio, video, presentations or emails. Within the organization data is usually recorded using transaction processing systems (TPS).

Information This involves the conversion of the data to the requirements of the end user. It is viewed by many as being structured data. It may be tailored to represent seasonal production outputs, quarterly sales comparisons, regional performance and consumer trends. This information then forms an integral part of the strategic development of the organization, provided it is made available in the correct place in a timely fashion. Data to information conversion is usually done using data mining processes made available by TPS systems.

Knowledge This may be best described as a certain level of understanding in a particular area which may be gained through cognitive experience. Knowledge is controlled with the use of management information systems (MIS) which provide the ability to make the correct information (pre-stored

analysed data) available (communication) to the right people in the right place (collaboration) and at the right time.

Wisdom This is generally accepted as being a combination of experience, cognitive learning and certain personality traits that provide a person the ability to make wise decisions. Wisdom has also got a lot to do with judgement where conclusions generally come as a result of sensible decisions and judgements from evidence, data and information made available to the person beforehand through MIS systems.

It is also clear that this information is vital to the sustainable development of the organization as it promotes a level of organizational holism and synergism. Information also provides managers with the ability to succeed within each trading region by providing strategic managers a concrete foundation on which to base their decisions with the help of certain resource management systems such as Decision Support Systems (DSS) and all the aforementioned organizational systems.

It is with the use of enterprise systems and platforms such as the internet that full supply chain visibility becomes possible and successful for all trading partners (Su and Yang, 2010b). ICT systems offer organizations the ability to look forward in the supply chain by providing them the ability to manage and create customer relationships. It is also possible to look backwards to evaluate the overall customer experience and analyse the organizations logistical protocols and assist in product recall should the system facilitate such an action. It is through the integration of enterprise systems and SCM that organizations can streamline their internal operations (Su and Yang, 2010a) and enjoy cost benefits (Sodhi and Son, 2009) (as well as a competitive advantage). An essential prerequisite of sustainability is the ability to integrate the whole supply network in relation to each product. This provides the capability to evaluate the full supply network and highlight any areas that may need attention. This process is only made possible with the availability of information, preferably in real time.

21.5 Conclusion

There are a number of key components in the sustainable development of an organization. These factors are built around the triple bottom line. The ability to incorporate this decision framework is key to the successful development of all organizations. It is also clear that there is no one straightforward solution to sustainability; it requires a multi-dimensional approach from all parts of the organization, from operations right up to strategic management. It also requires a multi-dimensional approach in terms of technology as was demonstrated via a merging of three key technology areas – RFID, biometrics and ICT – to create operational and informational synergies. Another key advantage of the merging of these technologies is their ability to convert

organizational data into a source of information which may form the basis of a strategy for the development of a sustainable competitive advantage.

For an organization to be truly sustainable it must be in a position to recognize its placement in terms of CSR. In order to do this an organization must be able to adopt a self-evaluating approach and take responsibility for all its actions including procurement, development, distribution and after sake care of all the products it offers, and it can only do this through the availability of information. It is now evident that this requires a significant effort in terms of time, technology and finance. More importantly it is now clear that sustainability should no longer be viewed as a financial burden as all indications lead to the conclusion that, when handled correctly it can in fact add value to the organization by adopting the correct strategy.

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22
Sustainable Food Consumption

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22.1 Introduction

Consumption is an activity which is determined by population growth, economic activity, technology choices, social values, institutions and policies (Yahya and Hashim, 2011). Food consumption is a basic need, essential for survival and can neither be renounced nor substituted. It has a significant impact on the environment since it involves a network of activities such as food production, transportation and consumption that use non-renewable resources and consumes many renewable resources at rates exceeding their replenishment (Foresight, 2011). These contribute to environmental problems like greenhouse gas emissions, erosion of farmland and excess wastage (Tukker and Jansen, 2006; Carlsson-Kanyama, 1998).

The world's population is projected to increase to over 9 billion people by the year 2050 (UN, 2011). In order to feed this population, it has been projected that the global food production should increase by 70%. However, this may not be the right way to proceed since it would magnify many of the problems with the current global food system (Tomlinson, 2011). Therefore, we need to rethink the strategy for global food production and consumption.

The principle of sustainability implies the use of resources at rates that do not exceed the capacity of our planet to replace them (Foresight, 2011).

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The Oslo Symposium on Sustainable Production and Consumption (1994) defined sustainable consumption as

> 'the use of goods and services that respond to basic needs and bring a better quality of life, while minimising the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not to jeopardise the needs of future generations'.

Sustainable consumption involves the consideration of the issues of human rights, equity, ecological impacts and political dimensions of sustainability in the production and consumption process, providing guidelines on how to reduce the social and ecological impacts of what we consume (UNESCO, 2002). It is a strategy which focuses on new techniques in managing the demand side of the economy while emphasizing environmental and social well-being (Haron et al., 2005). Hence, it may be inferred that sustainable consumption in the context of food would involve producing, choosing, consuming and disposing food commodities in an environmentally friendly manner to bring about social and environmental benefits.

Sustainable utilization of resources during food production combined with practical ideas for sustainable consumption will need to pave the way in tackling the problem of food security in a realistic and achievable manner. This chapter will review the issue of global food security, drivers and barriers that affect sustainable food consumption. Trends in the sustainable utilization of resources and future challenges will be discussed using the growing knowledge in this area by way of policy and academic literature.

22.2 Global food security

The current world population which is close to 7 billion is projected to reach 10.1 billion by 2100, reaching 9.3 billion by the middle of this century, according to the medium variant of the *2010 Revision* of *World Population Prospects* (UN, 2011), the official United Nations population projections prepared by the Population Division of the Department of Economic and Social Affairs. Nearly all of this increase will occur in developing countries.

The Food and Agriculture Organization (FAO, 2009a) defines food security as a 'situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (Schmidhuber and Tubiello, 2007).

Food insecurity results from inadequate access to sufficient and nutritious food (Moomaw et al., 2012). The lack of access can result from economic, physical or social barriers or any combination of these.

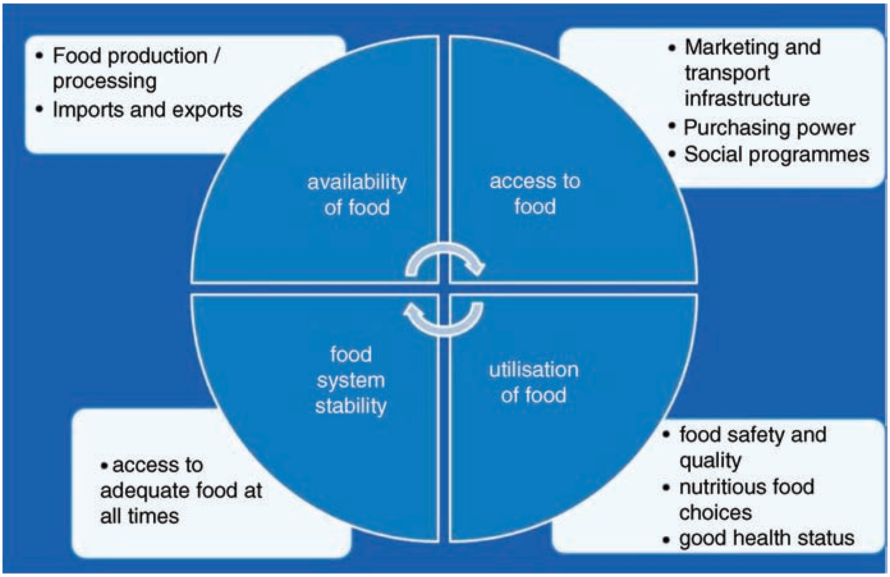

Figure 22.1 Four dimensions of food security (adapted from Ruane and Sonnino (2011)).

Figure 22.1 illustrates the four dimensions of food security as conceptualized by Ruane and Sonnino (2011). They assert that all the four dimensions must be fulfilled simultaneously for food security to be realised.

The recent Report on The State of Food Insecurity in the World (FAO et al., 2012) documented that 868 million people globally continue to suffer from undernourishment (Table 22.1), with around 2 billion people affected by micronutrient deficiencies. Undernourishment, especially in children, can have severe health effects such as slowing of growth, susceptibility to disease and shortened lifespan. It has been reported that more than 100 million children under the age of five are underweight and childhood malnutrition is killing more than 2.5 million children every year.

There are a new set of food security indicators published to measure food production, food prices, food expenditures, anthropometric indicators and volatility. The values for these indicators are available on the *State of Food Insecurity in the World* website (www.fao.org/publications/sofi/en/).

Solutions to achieve global food security include (Ruane and Sonnino, 2011):

1. Increase investment in agriculture.
2. Broaden access to food.
3. Improve governance of global trade.
4. Increase productivity and conserve natural resources.

Table 22.1 Undernourishment in the developing regions 1990–92 to 2010–12 (FAO et al., 2012)

	Number (millions) and prevalence (%) of undernourishment				
	1990–92	1999–2001	2004–06	2007–09	2010–12*
WORLD	**1000** **18.6%**	**919** **15.0%**	**898** **13.8%**	**867** **12.9%**	**868** **12.5%**
DEVELOPED REGIONS	**20** **1.9%**	**18** **1.6%**	**13** **1.2%**	**15** **1.3%**	**16** **1.4%**
DEVELOPING REGIONS	**980** **23.2%**	**901** **18.3%**	**885** **16.8%**	**852** **15.5%**	**852** **14.9%**
Africa	**175** **27.3%**	**205** **25.3%**	**210** **23.1%**	**220** **22.6%**	**239** **22.9%**
Northern Africa	5 3.8%	5 3.3%	5 3.1%	4 2.7%	4 2.7%
Sub-Saharan Africa	170 32.8%	200 30.0%	205 27.2%	216 26.5%	234 26.8%
Asia	**739** **23.70%**	**634** **17.70%**	**620** **16.30%**	**581** **14.80%**	**563** **13.90%**
Western Asia	8 6.6%	13 8.0%	16 8.8%	18 9.4%	21 10.1%
Southern Asia	327 26.8%	309 21.2%	323 20.4%	311 18.8%	304 17.6%
Caucasus and Central Asia	9 12.8%	11 15.8%	7 9.9%	7 9.2%	6 7.4%
Eastern Asia	261 20.80%	197 14.40%	186 13.20%	169 11.80%	167 11.50%
South-Eastern Asia	134 29.60%	104 20.00%	88 15.80%	76 13.20%	65 10.90%
Latin America and the Caribbean	**65** **14.60%**	**60** **11.60%**	**54** **9.70%**	**50** **8.70%**	**49** **8.30%**
Latin America	57 13.60%	53 11.00%	46 9.00%	43 8.10%	42 7.70%
Caribbean	9 28.5%	7 21.4%	7 20.9%	7 18.6%	7 17.8%
Oceania	**1** **13.6%**	**1** **15.5%**	**1** **13.7%**	**1** **11.9%**	**1** **12.1%**

*Projections.

22.3 Factors affecting sustainable food consumption

Food consumption is the amount of food available for human consumption. The consumer demand and pattern of food consumption has changed over the last few decades. There has been a rise in per capita food consumption globally and is projected to increase further in the future (Table 22.2). These changes have a significant impact on maintaining sustainable consumption. Economic

Table 22.2 Global and regional per capita food consumption (kcal per capita per day) (WHO, 2002)

Region	1964–1966	1974–1976	1984–1986	1997–1999	2015	2030
World	2358	2435	2655	2803	2940	3050
Developing countries	2054	2152	2450	2681	2850	2980
Near East and North Africa	2290	2591	2953	3006	3090	3170
Sub-Saharan Africa[a]	2058	2079	2057	2195	2360	2540
Latin America and the Caribbean	2393	2546	2689	2824	2980	3140
East Asia	1957	2105	2559	2921	3060	3190
South Asia	2017	1986	2205	2403	2700	2900
Industrialized countries	2947	3065	3206	3380	3440	3500
Transition countries	3222	3385	3379	2906	3060	3180

[a]Excludes South Africa.

growth assumptions together with the growth of population are the major determinants of projected food consumption.

Sustainable foods refer to foods produced and consumed in an economic, ecological and socially sustainable manner. They include fair trade food, organic food, local and seasonal food. Consumers seem to purchase and consume foods made by sustainable methods for hedonistic (e.g. taste, overall perceived quality), ethical (e.g. animal welfare) or environmental reasons (e.g. food miles travelled) (Onyango et al., 2007). Different disciplines such as economics, marketing, business strategies and consumer behaviour deal with the issue of sustainable consumption.

22.3.1 Key drivers for sustainable food consumption

Sustainable consumption is based on a decision-making process that takes the consumer's social responsibility into account in addition to individual needs like taste, price, convenience and health (Vermeir and Verbeke, 2006). Quite often, consumers make their food choices based on their nutritional or health needs, convenience, brand, their knowledge and understanding of food issues. In their study exploring the consumer attitude, behaviour and intention towards sustainable food consumption, Vermeir and Verbeke (2006) asserted that consumer's 'involvement with sustainability, certainty with respect to sustainability claims, and perceived consumer effectiveness have a significant positive impact on their attitude' towards buying sustainable products. In certain cases, consumers feel social pressure from peers to follow sustainable consumption trends.

A meat-based diet has a higher carbon foot print than a vegetarian diet. Based on the annual consumption per person, a vegetarian diet produces only about half the amount of Green House Gas emissions compared to a typical

meat-based Australian diet (Wright et al., 2009). Environmentally conscious consumers and those concerned about animal welfare issues may want to switch from a meat-based diet to a predominantly vegetarian diet.

Food is the main source of energy and healthy diets maintain healthy living, reducing the risk of diseases. Consumers increasingly are demanding food perceived as 'healthy'. These include foods with reduced amounts of salt, sugar, fat, calories and no additives. In addition, there has been a recent trend in foods with added benefits, called 'functional foods' that meet specific needs.

22.3.2 Barriers to sustainable food consumption

Consumers still face barriers towards adopting sustainable food consumption. These include price, convenience, information (including regulation of claims and labels, advertising and public campaigns), food choice and accessibility (Brown et al., 2009; Dzene and Yorulmaz, 2011) as highlighted in Figure 22.2. Negative attitude towards sustainable products will lead to lack of sustainable consumption (Dzene and Yorulmaz, 2011). Lack of clear information about sustainable products could have a negative impact on the decision-making process to consume sustainable foods. Also, habitual purchase behaviour could be a reason to exclude new products such as sustainable foods.

Figure 22.2 Barriers to sustainable food consumption (Brown et al., 2009; Dzene and Yorulmaz, 2011).

Low perceived availability and easy accessibility of sustainable foods is another key factor for consumers to be able to purchase and consume sustainable foods. Cultural context is very significant when it comes to adopting sustainable consumption. For instance, consumers from France were found to use local markets and purchase local produce more frequently (Brown et al., 2009). This research also highlighted that consumers feel that there is only a limited range of produce available and the quality was not always consistent. In addition, consumers from UK felt that the desire to eat out of season was a major barrier.

Consumers need to be educated regarding the conceptual understanding of how sustainable food products are measured to be able to make sensible choices. The sustainability credentials of food products are often measured in terms of Green House Gas emissions expressed as grams CO_2 equivalent per unit mass of product. This value is referred to as the carbon footprint of the product (Martindale, 2010) and is a good indicator of its impact on the environment. The larger the carbon footprint, the lower would be the sustainability credentials of the food product.

'Food miles' defined as the distance the food travels from farm to plate is another frequently used measure (see Chapter 20 for further elaboration on food miles and the practical implementation of this metric). According to this definition, locally grown and locally manufactured foods are more environmentally sustainable than products that have to be shipped from long distances. However, studies have shown this not to be always true. For example, it can be more energy efficient for a British household to buy tomatoes or lettuce from Spain than from heated greenhouses in the UK (Engelhaupt, 2008). Similarly, lamb from New Zealand is more environmentally sustainable with a lower carbon footprint compared to lamb produced in the UK (Saunders et al., 2006).

Life cycle assessment or analysis (LCA) is a tool to assess product impact and efficiencies during the life of the product from production through to consumption and disposal. Thus, LCA can be used to aid in sustainable food production and consumption (Moomaw et al., 2012).

22.4 Trends in the sustainable utilization of resources

In light of the rising world population and food consumption, it is important to produce and utilize the food resources in a sustainable manner in order to maintain global food security. The following are some of the measures suggested and carried forward by policy makers and different stake holders.

1. *Certification Schemes*

   Among the trends that are increasing in popularity is the certification scheme to improve the environmental standards of producers and

businesses. For instance, the global consumption of edible vegetable oil has increased by ~99 million tons between 1971 and 2010 (2012b, Koh and Lee, 2012). This has resulted in an increased demand for palm and soybean oil, both of which can be produced only in tropical places such as South-East Asia, Latin America and certain parts of Africa. To meet this growing demand, tropical forests are being destroyed and biodiversity is being lost. The Sustainable Palm Oil Roundtable (www.rspo.org) and the Round Table on Responsible Soy (www.responsible-soy.org) have developed certification standards to ensure the sustainable production of these oil seeds without having a detrimental effect on the tropical forests.

Similarly, organic certification of produce and livestock aims to encourage farming systems that have minimal effect of harming the environment, for example, the Soil Association (http://www.soilassociation.org).

2. *Reduction in the consumption of foods from animal origin*

Foods from animal origin contribute disproportionately high amounts of greenhouse gas emissions in CO_2 equivalent (around 18%) which is even more than the global 'transport' emissions (Steinfeld et al., 2006). The growing global population along with increase in affordability in many developing countries is resulting in a rapidly growing demand for animal products. Global meat production is projected to increase by more than two-fold between 1999/01 and 2050 (229 million tonnes to 465 million tonnes) and milk production from 580 to 1043 million tonnes. This will have a serious environmental impact in terms of land degradation, atmosphere and climate changes, reduction in biodiversity and water supply. Consumption of animal products will be unsustainable in the long run since large amounts of plant-based animal feed is required to produce small amounts of meat or milk; around 7 kg of grain for 1 kg of beef, 4 kg of grain for 1 kg of pork and 2 kg of grain for 1 kg of poultry (http://www.sustainweb.org/sustainablefood/meat_and_dairy_products_less_is_more/). The nitrogen fertilizers used to grow the animal feeds also contribute towards emissions of greenhouse gas nitrous oxide.

Consumers are encouraged to reduce their consumption of meat, dairy products and eggs since livestock farming is one of the significant contributors to greenhouse emissions and climate change (McMichael et al., 2007). The global mean meat consumption of 100 g/person/day has a ten-fold variation between high-consuming and low-consuming populations. Therefore, McMichael et al. (2007) propose a policy of 'contraction and convergence' that is, contracting the consumption levels in rich countries and increasing the consumption levels in poor countries. This would enable to combat price rises (thus helping with food security issues). In addition, consumers could also demand for these commodities to be

produced to good environmental and animal welfare standards, with lower emissions.

3. *Insects as alternate source of protein*

Entomophagy is the utilization of insects as human food (Premalatha et al., 2011). It has been practiced in many regions of Asia, Africa and America for a long time. Insects have been compared to livestock meat in terms of their nutritional content with 40–75% crude protein on dry weight basis (Klunder et al., 2012). However, insects produce lower greenhouse gas emissions per kg mass gain compared to conventional livestock, have higher feed conversion efficiency (i.e. are far more efficient in converting the feed to animal protein) and reproduce faster, with a faster growth rate. These make insects a very compelling source of sustainable food as the rising global population and economic growth increases the demand for protein rich foods. In terms of their consumption, Klunder et al. (2012) propose that insects can be eaten whole, in their native recognizable form or can be processed into a powder/paste or protein isolate and used to enrich foods in the place of soy or meat proteins. Perhaps, many countries could look into positively harnessing this source instead of trying to spend millions in getting rid of them as 'pests' from agricultural lands.

4. *Use of fish from sustainable stock*

Some species of fish such as cod, plaice, skate are deemed to be less sustainable and at risk. Consumers and manufacturers could opt for fish that are from sustainable sources like Pollock. The Marine Conservation Society (2012a) provides valuable information about the sustainability credentials of different types of fish using a traffic-light rating system (http://www.fishonline.org/fish-advice/avoid). Fish to eat are rated 1 and 2 while fish to avoid are rated 5 (Table 22.3). The lower (green light) rating is given where the fish has healthy stock and the harvesting methods are

Table 22.3 Rating system developed by Marine Conservation Society as advice for choosing the most environmentally sustainable fish.

1	Rating 1 (light green) is associated with the most sustainable produced seafood.
2	Rating 2 (pale green) is still a good choice, although some aspects of its production or management could be improved
3	Rating 3 (yellow) based on available information; these species should probably not be considered sustainable at this time. Eat only occasionally and check www.fishonline.org for specific details.
4	Rating 4 (orange) should not be considered sustainable, and the fish is likely to have significant environmental issues associated with its production.
5	Rating 5 (red) is associated with fish to be avoided on the basis that all or most of the above bullet points apply.

regulated to have minimum impact on the environment/habitat and non-target species.

Fisheries could use the Marine Stewardship Council (2012b) certification scheme and follow sustainable fishing practices. Businesses can also benefit by using seafood from such sustainable sources. By using the eco-label of the Marine Stewardship Council in their product, manufacturers and retailers can raise awareness in consumers and enable them to make informed sustainable choices. Capture fisheries and other renewable resources are maintained such that they do not get depleted beyond their capacity to recover.

5. *Reducing food waste*

Food waste is defined as 'wholesome edible material intended for human consumption arising at any point in the food supply chain that is instead discarded, lost, degraded or consumed by pests' (Sakai et al., 2012). A study commissioned by UN's Food and Agriculture Organization (FAO, 2011) reported that 'roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year'. This includes food loss and waste in the whole supply chain from initial agricultural production through to the consumption. Low-income developing countries experience food loss mostly during the early and middle stages of the food supply chain, mainly at post-harvest and processing levels and loss at consumer level is significantly lower (Figure 22.3). In contrast, in the middle to high income countries, food is significantly wasted at the consumer end, mainly due to poor purchase planning, strict adherence to 'best-before' dates and consumers' careless attitude towards wasting food. Wastage also occurs early in the food supply chains due to quality standards that reject superficially imperfect products in terms of size, shape and external appearance (e.g. bent appearance). Large proportions of such crops intended for

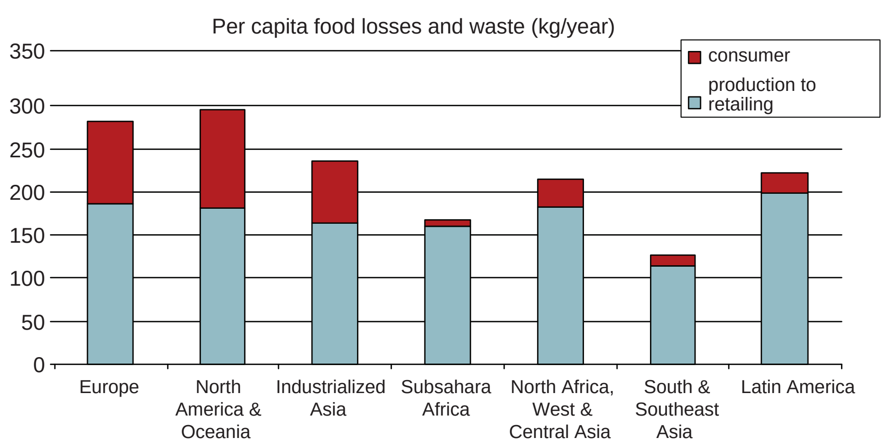

Figure 22.3 Per capita food losses and waste, at consumption and pre-consumption stages, in different regions (FAO, 2011).

human consumption get diverted as animal feed for far less value (Stuart, 2009). The food wasted at the consumer level in industrialized countries (222 million tons) is almost as high as the total net production in sub-Saharan Africa (230 million tons) (FAO, 2011).

A reduction in food wastage at the consumers' level can occur if there is a change in their behaviour in terms of reducing tendency to overbuy, following good food storage practices, demanding sustainable food to be sold by retailers and food businesses and supporting organizations that adopt sustainable food policy.

Food waste from food industries and large catering establishments (such as trimmings or products not conforming to commercial specification but safe, nutritious and palatable) can be redistributed through responsible schemes run by commercial or charitable organizations. A good example of this is FareShare (FareShare, 2009) in the UK. FareShare uses 'fit for purpose' surplus food from the food industry or retailers (that would otherwise be thrown away) to feed vulnerable people in the community, thus reducing food wastage and food poverty.

6. *Eat seasonal foods*

   Consumption of local, seasonal food ingredients would help to minimize energy used in food production, transport and storage. It would also provide the diverse nutrients required and hence with nutritional sustainability. However, buying food from low-income developing countries should be continued to mainly help sustain fair prices, good working conditions and create stable contracts for the workers in these vulnerable areas (Foresight, 2011). This would have a direct impact on maintaining the economy and hence, food security of such demographic regions.

7. *Avoid bottled water*

   At the industry level, efficient usage of water is being practiced by many food and drink industries through water efficient technologies, modifying design of equipment and processing, training staff, modifying cleaning procedures and measuring/monitoring water usage. At the consumer level, consumers are encouraged to drink plain or filtered tap water, to minimize transport and packaging waste.

8. *Sustainable Diets*

Sustainable Diets are

> 'diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimising natural and human resources' (FAO, 2009b).

The Mediterranean diet is an illustrative example of such a diet, being low in meat, sugar, saturated fats and high in fruits and vegetables (Burlingame and Dernini, 2011)

The UK Sustainable Development Commission has looked into many of the measures towards sustainable consumption in terms of their possible impacts on public health, social inequalities, environmental and economic sustainability (Table 22.4). Reducing food and drink consumption stands out as a very effective guideline towards achieving environmental and economic sustainability.

Sustainability also extends to financial and human capital. The Foresight Report (2011) asserts that food production and economic growth must support a sustainable economy, creating sufficient wealth to maintain a viable and healthy workforce. Skills must be transmitted to future generations of producers. Sustainability also entails resilience, such that the food system, including its human and organizational components, is robust to transitory shocks and stresses. In the short to medium term, non-renewable inputs will continue to be used, but to achieve sustainability the profits from their use should be invested in the development of renewable resources (Foresight, 2011).

Table 22.4 Summary of impacts of framework guidelines for 'sustainable' and healthy diets (UK Sustainable Development Commission, 2009)

	Framework guideline	Public health	Environmental sustainability	Economic sustainability	Social inequalities
1	Consume less food and drink	+	+	–	+
2	Accept different notions of quality	o	+	–	o
3	Accept variability of supply	±	±	o	±
4	Shop on foot or over the internet	o	+	o	o
5	Cook and store food in energy conserving ways	o	+	o	o
6	Prepare food for more than one person and for several days	o	+	o	o
7	Reduce food waste	+	+	–	o
8	Reduce consumption of meat and dairy products	±	±	–	+
9	Reduce consumption of food and drinks with low nutritional value	+	+	–	+
10	Reduce consumption of bottled water	o	+	o	o
11	Increase consumption of organic food	o	±	+	–
12	Eat seasonal, field grown fruit and vegetables	–	+	–	o
13	Eat fish from sustainable stocks	–	±	o	+

+ some evidence of positive impacts
– some evidence of negative impacts
± some evidence of both positive and negative impacts
o *no evidence of impacts*
Note: 'no evidence of impacts' does not equate to no potential impacts.

22.5 Future challenges

Many consumers want to be sustainable but cannot action on it. There seems to be a value – action gap. It is imperative to market sustainability to help consumers make informed decisions. Clarity in communicating the message is important in changing the behaviour. Initiatives such as information about the local suppliers, origin of produce at point of purchase make consumers feel good about making sustainable consumption choices and can encourage them to continue to make these choices.

In order for consumers to make sustainable food choices, a product's environmental friendliness could be communicated in a simple, understandable manner. Food manufacturers could help educate consumers about buying products made from sustainable sources. Product labels detailing their sustainability credentials would enable consumers to make informed and sustainable buying decisions. Tanner and Kast (2003) observed that many supermarkets focused on the production details (organic) but ignored other product features that significantly affect sustainability like conservation, packaging, origin of the product. For instance, packaging can be used as a conduit. Tobler et al. (Tobler et al., 2011) indeed suggested that product labels containing Life Cycle Assessment information could facilitate ecological consumption. However, food manufacturers and retailers might not be willing to do this voluntarily. Such labels, therefore, might need to be regulated by law.

Increasingly, the food supply chain is becoming globalized, that is, food is grown in one geographical area, processed in another and may be consumed in a different part of the world. Therefore, it is imperative that efficiency in waste management is effective in all parts of the supply chain. In the low income developing countries, the harvest techniques, farmer education, storage facilities and cooling chains will need to be improved (FAO, 2011). Food waste is a significant problem in the developed countries at the retail, service sector and domestic household level. Quite often, food is thrown away if it has no commercial value or by the 'use-by' date mainly to minimize the risk of food poisoning. Reducing food waste will be quite difficult since consumers will continue to demand safe food that is governed by sell by and use by dates, packaging, preservation and chill chains (Martindale, 2010). The challenge will be to educate consumers that they can safely use the low risk commodities like fruits and vegetables beyond the use by dates to reduce waste. In addition, engineering and technology could be used to provide creative solutions to bring added value to the food waste by producing fuel such as bioethanol (Kim et al., 2008), feed and fine chemicals from them (e.g. antioxidants, chitin, poly-L-Lactate biodegradable plastics from food waste) (Ghorbel-Bellaaj et al., 2012; Spigno and De Faveri, 2007; Sakai et al., 2012).

Research indicates that food price is an important factor when consumers make their food choices (Steptoe et al., 1995; Drewnowski and Darmon, 2005). Studies have shown that consumers chose healthy foods when their prices were

reduced (French, 2003; Horgen and Brownell, 2002). A similar pricing strategy could be used in order to encourage sustainable consumption. Studies (Gan et al., 2008; D'Souza et al., 2006) show that consumers are less likely to purchase environmentally friendly (green) products if they are more expensive. Alternatively, a carbon tax could be levied on food products with high food miles making such products less attractive for consumers. Altering consumers' attitudes, belief systems, knowledge and behaviours would probably facilitate the acceptance of such policies, and stimulate lifestyle changes and changes in the political and economic system (Tanner and Kast, 2003). Some companies follow premium – price model, charging more for sustainable products. However, food manufacturers could explore sustainable sources of ingredients and modes of processing. This would not only project a positive image of these businesses to consumers but will also help to offset effects of price rises.

Linking cause and consequence is important to change consumer behaviour. To motivate behavioural changes, consumers must be convinced that their behaviour has an impact on the environment or will be effective in fighting environmental degradation (Roberts, 1996). Indeed, research findings reveal that consumers who are environmentally conscious are more likely to purchase green products (Gan et al., 2008). Sustainable and ethical food consumption can be stimulated by emphasizing consumer's personal relevance and involvement, informing them about product availability and perceived consumer effectiveness through effective communication and provision of information (Vermeir and Verbeke, 2006). Also the concept of 'sustainability' could be integrated with 'quality' through good marketing strategies to allow consumers to perceive the two synonymously.

Marketing sustainable purchase and consumption is crucial for the success and uptake of sustainable food consumption by consumers. To this end, targeting the main decision makers in food commodity purchase and utilization at the domestic, service and industry level would be beneficial to implement the changes. Tanner and Kast (2003) found women to be the gatekeepers at a domestic household level with the potential to implement changes.

One of the main challenges for policy makers and governments is the rising movement of 'food sovereignty', initially directed at the globalization of economy and agriculture (Glipo and Pascual, 2005). The international farmers' movement, La Via Campesina, officially launched the idea of 'food sovereignty' at the 1996 World Food summit as an opposing concept to globalization and challenge to food security. It is defined as:

> Right of peoples, communities, and countries to define their own agricultural, labour, fishing, food and land policies, which are ecologically, socially, economically and culturally appropriate to their unique circumstances. It includes the true right to food and to produce food, which means that all people have the right to safe, nutritious and culturally appropriate food and to food producing resources and the ability to sustain themselves and their societies.

In recent times, the concept of food sovereignty has gained the support and adherence by governments and NGOs (Glipo and Pascual, 2005). This may be due to its alignment with the goals of sustainable production and consumption. Many policy reforms have been suggested which include promotion of domestic food production to achieve food self-sufficiency, regulation of trade to ensure fair prices for small farmers, increased domestic support for sustainable agricultural practices to quote a few.

There are three types of policy instruments available at governmental level to address the issue of sustainable consumption and production (Mont and Plepys, 2008). These are:

- Administrative or regulatory instruments: usually applied to producers (e.g. pollution control, product standards).
- Economic instruments (tax reforms, product charges): affect producers but are directed towards final consumers.
- Informative instruments: used for consumers through for example, awareness raising campaigns, education and eco-labels and for producers through labelling schemes or voluntary initiatives.

Mont and Plepys (2008) propose that 'governments need to change the institutional frameworks in society and create conditions in which less materialistic aspirations prevail, supported by producers delivering less resource-intensive products and services'. However, changing the consumption pattern and reducing material consumption would be a major challenge since this would clash with economic growth which is every government's priority. Addressing consumption issues would require a multidisciplinary approach with inputs from economics, sociology and psychology, taking into account political, technological and environmental factors.

Development of sustainable food consumption would require balancing between the environmental impacts of consumerism, fostering sustainable development, meet socio-economic goals and political agendas. It needs to have a concerted action by governments, businesses and consumers at the global level.

22.6 Conclusion

Sustainable consumption is at the forefront of environmental and economic policy makers. It incorporates global issues of poverty, human rights, fair trade, environment, conservation, development and peace. It can be achieved by motivated consumers and a radical change in the private production and marketing sectors. It will require a multi-stakeholder approach involving public policy, government regulations, non-governmental organizations, food industry, marketing innovation, consumer groups and voluntary initiatives from individual consumers. Tackling sustainable food consumption at the

national level can be a challenge in itself and will require the cooperation of all the stakeholders including international policy makers. Different nations, cultures and communities have the right to interpret what sustainable consumption means to them across the social, ecological, political and economic dimensions of sustainability. The ultimate aim of sustainable food consumption is to provide a good quality of life, while reducing the environmental, economic, social and political impacts of food production and consumption.

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Index

abattoirs 173, 179, 186
abiotic depletion potentia (ADP) 201
acceptable daily intake (ADI) 110, 112, 115
accumulation 241–2, 283, 357
acid, lactic 140, 230, 233, 237, 256, 288
acidification 64, 78–9, 84, 95, 99, 140, 196, 302, 449
acidic electrolyzed water (AEW) 233–4
acidified sodium chlorite (ASC) 231, 251, 253, 258, 265
activated carbon 287, 298–9, 310, 409
additives 113–14, 183, 219, 314, 524, 544
adsorption systems 483, 485
adults 114, 283–4
AEA Technology 206, 214, 216, 473, 476–7, 491, 494, 500, 508, 511–12, 517
aerosols 181–3, 349
Africa 379, 381, 383, 542–3, 546–7
agents, physical 110, 112–13, 120
agri-food sector 55, 59
agricultural organization 56, 122
Agricultural Sustainability Institute (ASI) 214, 491
agricultural systems 36, 54, 57, 60, 88–9, 100, 102, 519–20
agriculture 52, 54–5, 57–8, 60–2, 89, 91, 101–2, 123, 260, 263–5, 318, 334–5, 459–60, 517, 535–6
Agriculture and Food Science Centre 63, 103
Agricultural and Horticultural Development Board (AHDB) 172–3, 190
agriculture organization 103, 123, 191–2, 215, 318, 433, 460, 540, 548, 554
Ahvenainen 220–3, 225, 250
air temperature 200, 205, 281, 387, 394
air transport 511
air velocity 205, 275, 277, 395–6
Allende 219, 221–2, 225, 231, 240–1, 243, 247–8, 250–1, 260, 264
allocation 69, 73–4, 80
alternative agri-food chain management systems 88
alternative food production systems 94
aluminum 41, 348–9
ambient 451, 466, 479, 483, 488–9, 491
ambient temperatures 51, 135, 142–3, 211, 379, 389, 464, 467, 476, 479, 482–3, 489–90, 492–3, 504
American Public Health Association (APHA) 316, 333

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American Society for Agricultural and Biological Engineering (ASABE) 535
American Society of Heating 206, 214, 476, 491
ammonia 156, 372, 409, 473
anaerobic digestion 31, 87, 389, 447–9, 457
analysis, compositional domestic food waste 461
animal food manufacturing 382
animal food products 176, 193
animal health 111–12
animal origin 47–8, 188, 546
animal products 47, 85, 108, 174, 176, 546
animal protein 47–9, 188, 547
animal protein food processing 81
animals 3, 43, 66, 95, 108, 111–12, 115, 147–8, 169–70, 178–9, 182, 288, 302–4, 318–20, 529–32
  bovine 531, 535–6
Animal Science Journal 59
antioxidants 52, 245–6, 251, 255, 263, 265, 288, 322, 551, 555–6
AP 201, 356–7
appetite 25, 36, 191–2, 335, 554, 556
apples 231, 233, 237, 245–6, 263
Application of emerging energy-efficient technologies 394
Application of emerging energy-efficient technologies pasteurization 391
Application of food industry waste 60
Application of sustainability concepts 6
applied energy 398, 492
applied research 11–12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 261
applied thermal engineering 310–11, 399–400, 429–30, 496
approaches 12, 19, 22, 24, 33–4, 65, 75, 85, 104–5, 136, 157–9, 209, 244, 424, 500–501
  conceptual design 424
  food system level 22
  multi-dimensional 340, 534
  technological 525, 527, 529, 531, 533
aquaculture 51, 114, 215, 218, 304
Archer 203, 209–10, 214
ASEAN Crops Post-Harvest Programme 290, 292, 294
Asian Institute of Technology 215, 289, 292, 295
Asian Journal of Food and Agro-Industry 61
assessment
  qualitative 108
  quantitative 108–9, 112
assessment methods, environmental 64–5
assessment of energy use and greenhouse gas emissions 18
assessment tools, environmental 65
assessors 107, 109, 115–16, 119
assets 314, 493, 525–8, 533
assumptions 74–5, 81, 86, 106–7, 110, 115, 320, 503, 512–13
atmosphere 139, 156, 173, 181, 185–6, 226, 241–2, 283–5, 303, 306, 501, 546
atmosphere packaging, modified 42, 86, 219, 222, 251, 255, 258–60, 266
attributes 11–12, 19, 21–2, 73, 248, 322, 325, 449
‘attributional’ LCA (ALCA) 69–70
Australia 38, 42, 57–8, 83, 89–91, 102, 153, 155, 159, 171–2, 217, 318–19, 481–2, 491–2, 496
Australian food industry 474
Australian food processing industry 434
Automated design of discontinuous water systems 431
average energy input and CO_2 emissions 505

bacteria 105, 107, 117, 202, 234, 256–7, 370, 373, 482
bakeries 147, 149, 270, 382–3, 440, 491
Bangkok 290–2, 294–5
barley 295, 302–3, 310

barriers 326, 426–8, 447, 524, 540, 544
Barros 204, 210, 214
Barry-Ryan 222–3, 252, 256, 260, 262
bars 243, 284–5, 299, 303, 373
batch systems 424–5
bedding 178–9, 181–2
beef 13, 20, 49, 51, 59, 176–7, 196, 355–6, 384, 396, 451, 481, 492, 546
beer 55, 301–7, 309, 311, 373–4, 385, 404
beer life cycle 306–7
bench mark dose (BMD) 112, 115–17
Bentham 481–2, 491
BFFF *see* British Frozen Food Federation
Billiard 206, 209, 214, 476, 480, 491
bioavailability 236, 322
biochemical oxygen demand *see* BOD
biofuels sustainability assessments 294
biogas 45, 157, 166, 289, 296, 304–5, 389, 447, 456
Biological metabolism of wastewater 409
biomass 274, 285, 299, 310, 380
bleeding 173, 178–9, 181–2
blood 95, 175–6, 178–82, 210, 415, 528
bench mark dose (BMD) 112, 115–17
BOD (biochemical oxygen demand) 44, 94, 130, 160, 173–4, 176, 185, 403, 405, 409–10, 413
boilers 154–5, 157, 305, 387, 403–4
boiling 137, 302, 306
boxes 15, 22, 29–31, 42, 202–3, 227, 504–8, 515
Brackett 221–2, 224, 253
breweries 288, 303–8, 310–11
brewer's spent grains *see* BSG
brewing 6, 271, 294, 305, 309–10, 373, 403, 443
brewing operations 302–3
brines 404, 421, 473
British Food Journal 121, 333, 335, 518,'555
British Frozen Food Federation (BFFF) 29–30, 35, 207, 214, 469, 491
British Industrial Biological Research Association 123–4
British industry 385–6
Broadwater 369–71, 374
brown rice 39, 42, 271–2, 274
  germinated 45, 271, 274, 291–2
browning 220, 222, 232, 240, 242–3, 254, 262
brewer's spent grains (BSG) 288–9
buildings 156–7, 207, 321, 330, 369, 478, 525–6
Bulletin 90, 162, 214–15, 218, 491–3
businesses 19, 33–5, 55–6, 65, 73, 326, 390, 438, 508, 525, 529, 532, 536, 546, 552–3
Butler 59, 192, 535–6, 555
butter 128, 133, 143–6, 149, 151, 163, 165, 327, 384
buttermilk 129, 133, 137, 144–6, 149, 160, 163, 166
by-products 99, 128–9, 132, 144, 146, 148–50, 160,191, 210, 234, 244–7, 249,252,256,260,263,294,296,427
by-products of plant food processing 264

cabinets 208, 470–71, 478
Codex Alimentarius Commission (CAC) 104–5, 107, 112–14, 117, 122–3, 429–30
caffeine 296, 298–300, 309
Cairns 206, 214, 477, 491, 502–3, 517
California Department of Public Health (CDPH) 227, 253
campaigns 170, 455–7
Campylobacter 117, 177, 481–2
Canadian Council of Ministers of the Environment (CCME) 341, 353, 359
Canadian food 58, 432
canals 55, 90, 94, 98, 101
canning 95, 202, 204, 271, 313
canning operations 204–5
capacity 42, 100, 136, 158–9, 275, 277, 318, 320–21, 323–4, 328, 358, 457, 464, 503, 539

capita 41, 47, 434
carbon 12, 18, 23–4, 33, 42, 285, 409, 459, 474, 477, 500, 507–8, 517
carbon dioxide 58, 96, 100, 128, 251, 283–4, 290, 293–4, 476, 506
  high 251, 253, 283–4
carbon dioxide concentration 279, 283–4
carbon emissions 7, 157, 205–6, 307, 329, 476, 500–501, 504–8, 515–16
carbon footprint 2, 4–5, 12, 18, 22, 28–9, 54, 67–8, 85, 88–9, 127–8, 155–8, 196–7, 204–6, 545
  of canning operations 204–5
  of fishing operations 197, 201
Carbon Reduction Commitment (CRC) 33–4, 263
Carbon Trust 12, 35, 67–8, 88, 505–6, 517
carcass meats 184, 465
carcasses 95, 173, 175, 178–81, 183–4
Carlsson 46, 49, 55
Casani 408, 416, 418–20, 426, 429
Castells 59, 101–2
catching 196–7, 201, 209
cattle 14, 139, 171, 173, 175–6, 178–9, 319, 531
Centre for Design (CfD) 340, 351
Centre for Environmental Science 359–60
Centre for Food Innovation 11, 23
CEO Water Mandate 407, 429
Cereal Chemistry 58, 290–1, 293–5
Cerutti 98–100
Centre for Design (CfD) 340, 351
Chang 425, 429–30
change 4, 12–13, 18, 20, 24, 26, 33, 36, 42, 51, 59, 69–71, 84, 160, 320
  climatic 61, 192–3, 211, 464, 474–5, 477, 479, 490
  global 2, 4
changing structure of global food consumption and trade 35
Chapman 266–7, 310
characterization 79–80, 115, 375
Charron 481–2, 492–3
cheese 77, 82, 128, 132–3, 140–1, 145–6, 152, 162–3, 356, 384, 421, 457, 480
  manufacture of 140–1, 146
chemical oxygen demand (COD) 44, 94, 175, 403, 411, 415
  COD content 416–17
  COD load 179–80
chemicals 32, 72, 77, 107, 111, 115, 121, 123, 184, 279, 357–8, 364, 372, 416–17, 420–21
  oxygen demand *see* COD
  synthetic 249, 279
  toxicology 123–4
chilled process water 156
chilled sea water (CSW) 201
chilled transportation 142
chilling 134, 156, 174–5, 178, 180, 183, 192, 202–3, 216, 378, 390, 395, 397, 504, 507–8
  primary 197, 475, 480, 496
chilling system, counter-current water 466
China 15–16, 27, 50, 171–2, 187–8, 193, 358, 438, 512, 519
chlorine 180, 229–30, 233, 236–7, 259–60, 263, 265, 364–5, 369, 373–4, 410–12, 415, 421–2
  free 234, 236
  residuals 411–12
chlorine dioxide 252, 254–7, 260–2, 264–5, 412, 415, 422
CIAA 25, 35, 403, 417, 420, 429
citric acid 224, 232–3, 251–2, 255, 266
citrulline 247, 258, 262
classification 78–80, 89, 223, 291, 351, 436
clean-in-place (CIP) 136, 138, 152–3, 306, 364–6, 372, 421, 431
  CIP systems 155, 372, 373–4, 420–21
cleaner production (CP) 189, 193, 289, 296
cleaner wastewater 417
  obtaining 416
cleaning 6, 136, 152–4, 158, 163, 165, 175–6, 180–5, 203, 351, 363–70, 372, 373–4, 417, 431–2
cleaning agents 136, 138, 159–60, 364, 367, 372
cleaning-in-place 165, 366, 431
cleaning operations 369, 416–17

cleaning procedures, industrial 371
cleaning process 210, 364–7
cleaning programme 365
cleaning solutions 153, 373, 417, 421
cleaning strategies 364–5
climate change 2, 4, 11, 51–2, 55–62, 78–9, 191–2, 215–16, 287, 317–18, 334–5, 482–3, 491–3, 496, 554–6
Climate Change Agreements (CCAs) 34
climate change impacts 58, 481
Climate Change Levy (CCL) 34
closed systems 366–7
CO_2
  kPa 241–3
  supercritical 147, 395
CO_2 emissions 34, 42, 51, 79, 90, 130, 157, 178, 181, 207, 476–7, 505, 509–10, 512, 514–15
CO_2 equivalents 20, 67, 128, 132
Code of Federal Regulations (CFR) 193, 231, 253, 255
CODEX Alimentarius 408, 416, 429–30
Codex Alimentarius Commission (CAC) 104–5, 107, 112–14, 117, 122–3, 429–30
coefficient of performance (COP) 364–5, 467, 485
coffee 21, 296–8, 300, 302, 304, 311, 383, 385
coffee grounds 299–300, 309
coffee husks 296, 299–300, 309–10
coffee industries 296, 300, 302
coffee processing 299, 301, 308
coffee production 296–7, 310
coffee pulp 296, 298–9, 309
coffee waste 299–300
cold chain 156, 213–15, 221, 451, 453–5, 463–4, 491–4
cold-chain management 211, 465, 467, 469, 471, 473
cold stores 156, 207, 468–69, 478
coldstorage 484
Coleoptera 289–91, 294
collaboration 147, 160–1, 193, 327–8, 426–7, 443, 534
collection 56, 148, 152, 154, 158–9, 300, 343, 394, 448–9, 456–7, 533
  of rainwater 154, 307
collection and reprocessing systems for the packaging 346
Collett 465–6, 492–3
combustion 157, 286, 310, 389
Commercial Service Cabinets (CSCs) 208, 469, 478–9
commodities 62, 214, 219, 221, 227, 230, 241, 281, 314, 320, 326, 475, 546
Commonwealth Scientific and Industrial Research Organisation (CSIRO) 492
communication 33, 86, 89, 118–21, 131, 150, 356, 427, 430, 526–7, 534
  process of 119
communities 44, 154, 170–1, 173, 316, 323, 330–32, 344, 503, 523, 549, 552, 554
companies 12, 18, 20–1, 28–30, 85, 315, 324–5, 327–30, 332–3, 357, 407–8, 452–4, 457–9, 486, 532–3
  most 66, 77
comparability 68, 70–1
comparative energy 61, 496, 556
competitors 131, 521, 523
components 64, 66, 71, 73, 79, 99, 105, 110, 112–13, 118, 185, 189–90, 220, 227, 245
  essential 15, 527, 529
compost 435, 446, 448–9
composting 31, 43, 45, 210, 351, 447–9, 457
compressed air 201–2, 210, 224, 387
compressed air systems 387–8
compressors 187, 201, 212, 387–8, 391, 397, 404, 465, 472, 485
computers 307, 535–6
concentrations 52, 112–14, 136–8, 159–61, 165, 175, 224, 228, 230, 235, 237, 245, 272, 283, 318
condenser 391, 395–7
conduction 202, 275–6, 294
conduction heating 276
Conesa 241–2, 253, 260
'consequential' LCA (CLCA) 69–70

conservation and recycling 88–90, 216, 310, 428, 432, 459–60
consumer acceptance 277, 281, 334
consumer attitudes 36, 41, 336, 543
consumer awareness 120, 456
consumer behaviour 25, 34, 40, 353, 554
consumer conceptions of processed food 314
consumer confidence 52, 121, 530
consumer demands 18, 20, 40, 54, 324, 500, 542
  changing 319, 326
consumer energy conservation opportunities 28
consumer food choices 17
consumer groups 118, 553
consumer level 41, 152, 548–9
consumer preferences 53, 150, 321
consumer science 25, 34
consumer stages 40, 87, 204
consumer technology 1, 363, 539
consumer trends 449, 533
consumer unit 351
consumers
  conscious 128, 544
  demand 39, 187, 219
  final 439, 553
  fresh-cut food 248
  green 131, 165, 555
  help 53, 551
  high water 175
  international food trade benefits 46
  large energy 379, 382
  meeting 327, 524
consumption
  average energy 208, 466, 478
  delivered energy 380
  higher energy 270, 307
  industrial energy 274, 385
  levels 546
  reducing energy 378, 470
  refrigeration energy 486, 490
  resource 317, 332
  total energy 158, 354, 377, 379, 381, 386, 474
  vegetable 219
consumption patterns, changing food 49
consumption processes 12, 540
contact 152, 182, 203, 224–5, 228, 234–5, 364, 404
contamination 45, 113, 182–3, 222, 224, 227, 230, 265, 349, 364–6, 373–4
continuous monitoring 113, 115–16, 289
control systems, national food 123
convection heating 276, 292
convenience 95, 150, 184, 286, 313–14, 322–3, 345, 348, 543–4
conventional method 154, 272, 274
cooling 4, 134, 137, 142, 145, 152, 174–5, 183–5, 203, 388, 396, 403–4, 413–14, 416–17, 483–5
  ambient 466
  large industrial food 473
cooking time 282
cooling systems 305–6, 485
cooling water temperature 200
cooperation 43, 406–7, 554
co-products 14, 31, 72, 74, 77, 271, 285, 288
Corkery 530, 532, 535–6
coroba slices, thin layer drying of 394, 398
Corporate Social Responsibility (CSR) 2, 21, 26, 158, 327, 333–4, 407, 432, 522, 535
correlation 509–10, 513–14, 516
costs 12, 46, 63, 98–9, 151, 153–5, 200, 326–7, 329, 333, 348, 388–9, 417–18, 426, 466–8
Coulomb 213, 215, 463, 473–4, 492
Council Directive 100–1, 406, 430, 460
countries 46, 50, 120, 148–9, 170–3, 176–7, 189–90, 225, 322–6, 358, 405–6, 437, 440–41, 447–9, 512–13
  selected 171–2
CP *see* Cleaner Production
cream 128, 132–3, 143–6, 148–9, 151
CSIRO Home Energy Saving Handbook 38, 556
cumulative primary energy 354
curing 95, 175, 183–5
curing process 185

current concepts 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38
current concepts and applied research in sustainable food processing 11
customer relationship management (CRM) 529
customers 12, 18, 62, 319, 332, 334, 441–3, 449–50, 452, 455–8, 501–4, 506, 514–16, 521–2, 524
cycle
  absorption refrigeration 396
  adsorption refrigeration 397
  novel refrigeration 395, 397, 400

dissolved air flotation (DAF) 410, 415

Electrolyzed water (EW) 233–4, 250, 252, 256–9, 262, 265–6, 421
Environmental Impact Assessment (EIA) 63, 90, 94, 96–100, 102
Environmental Product Declarations (EPD) 65–7, 87
  developing 87
Environmental Protection Agency (EPA) 43, 55, 106, 109, 175, 230, 254, 335, 400, 434
EPC C1G2 528
  EPCglobal 527, 535
  EPC Global network 536
  EPC network 529
EPCTM Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID 535
EPIC Nutrient Database (ENDB) 37
epidemiological studies 112, 219, 261
  studies, various 111
epidemiology 111, 265, 335, 492
epidemiology & infection 494
EPS 79
equilibrium atmospheres 226
equipment 137, 154, 156–7, 169, 175, 178, 180–1, 184, 200, 210, 301, 365–7, 378–9, 404, 420–21
  computer-controlled 157
  conveyor 187
  costly 284
  end-use 387
  including 72
  including subsidized 157
  inefficient 203
  jacketed 154
  maintaining energy-efficient 211, 465
  processing plant 365
  refrigerating 214, 216, 491, 493
  right 387
  rotary tumble 485
  scraping 210
  ultraviolet analyser 371
  wet 371
equipment and systems for comfort and food preservation 215, 493
equipment cleaning-outof-place 371
equipment control 157
equipment failure 453
equipment housings 157
Ernest Orlando Lawrence Berkeley National Laboratory 494
erosion 4, 318, 539
ERP systems 529, 537
errors 324, 445
Erwinia carotovora 234
Escherichia coli 231, 254, 261, 265, 370
Escherichia coli O104, producing 264
Escherichia coli O157 227, 230, 251, 253, 257, 264–6
Escherichia coli serotype O157 253
ESF-COST 36
essential oils 237, 253, 256, 264
establishing contracts 315
establishing fairtrade agreements 327
Establishment of Industry Advisory Committee 351
estimated energy value 475
estimated payback 386
estimated shelf life 280
estimates, numerical 108
estimating distributions 121
estimation of Vmax values 243
estimations
  initial 20
  maximum likelihood 109
  quantitative 114
  statistical 454

ethanol 227, 287, 395
  grain-based 288
  industry 288
  processing 285
ethical credentials 21
ethical impacts 46
ethical regard 525
ethics 334
Ethiopia 300
ethyl acetate 299
ethylene 226, 265
ethylene production 256, 356
  increased 220
eugenol 237, 266
Eunomia Research 460
Eurest 460
Eurest Services Sweden 460
Eurest-Services-Sweden-Goes-Green 460
Eurogroup 190
Europe 35, 84, 114, 131, 152, 177, 207, 228, 304, 319, 367, 402–3, 416, 437, 448
Europe America Asia 47
Europe and North America 41, 402
Europe North 548
European adults 49
European agriculture 36
European Commission (EC) 86, 96–7, 100, 107, 112, 130, 193, 215, 360, 406, 430, 436–8, 458, 460
European Commission
  European Commission Directorate Generale- JRC Joint Research Center 430
  European Commission Regulation 455
  European Commission's Packaging and Packaging Waste Directive 358
  European Commission Standing Committee on Agriculture Research 122
European Communities 430
European countries 176, 192, 379, 399, 402, 494–5
European dairy industry 166, 399
European Directives and Government regulations 30
European end-user nutrient database 37
European Food Safety Authority (EFSA) 108, 112–14, 117, 122
European food sector 86
European Food Sustainable Consumption and Production 86
European Food Systems 22, 36
European Impact of Products (EIPRO) 170, 193
European milk production 91
European Outlook on Water Use 430
European Parliament 430, 460, 536
European Parliament and Council 100
European Parliament and Council Directives 100
European perspective 263
European Platform on Life Cycle Assessment (EPLCA) 196, 215
European Union (EU) 59, 96–7, 100, 120, 130, 171, 190, 228, 244, 249, 339, 358, 379, 436–7, 460
  directives 96, 100–1, 353, 455
  emission standards 477
  Emissions Trading Scheme 34
  environmental impact assessment (EIA)
    directive 96
    procedure 97
  Environmental Technology Action Plan 428
  Regulation 364
  Standing Committee on Agriculture Research (SCAR) 103–4, 122
Eurostat 244, 254
Eurosurveillance 264
eutrophication 44, 64, 78–9, 84, 91, 95, 187, 356, 449
eutrophication potential (EP) 44, 91, 196, 201, 356–7
  marine 287
eutrophication of surface water 501
eutrophication potential 196, 201
eutrophication potential of food consumption patterns 91

evaluation 58, 67, 75, 80, 88, 91, 99, 101, 107, 115, 118, 124, 174, 196, 258
  of allergenicity 56
  alternative sanitizers 250
  costly experimental 226
  economic 517
  of indicators 91
  internal 524
  multi-criteria packaging 359
  quantitative 108, 113
  reliable 418
  of retinal imaging technology 535
  process 80, 107, 116
  of sanitizers 261
  science-based 105
  of value-added components of dried distiller's grain 291
evaporated milk 137
  recombined 148
evaporation 137–8, 144, 378, 387, 390, 394, 397, 408
evaporation practice 386
evaporator coils 489
  efficient 489
evaporator fans 213, 489
evaporator units 488
evaporators 137–8, 391, 394–7, 466, 472
  multi-effect 138
evidence-based case studies 509
evisceration 173, 178–81, 183, 187
evisceration area 183
evisceration line 183
evisceration machine 183
evolution 226
evolution of microbial 267
examples of LCA databases 77
examples spanning 67
exceed adhesion 368
excess caffeine 298
excess hull 298
excess products 324
excess wastage 539
exchange
  interactive 118
  ion 147
  limiting information 326
  transparent 119
exchange information 119
exchange resin 409
exclusion, explicit 73
executive summary 335
exergetic performance assessment 398
exergy analyses 309, 394, 397–9
  conducted 394
exergy analysis of industrial pasta drying process 399
exeter 499
exhaust air 139
expansion 101, 169, 372
  colonialist 313
  global 532
expansion demands 523
expansion valve 391
expense 44, 88, 111, 201, 317, 327, 389, 453, 530
expensive materials 342
experience
  cognitive 533
  difficulties consumers 331
  recycling food waste 461
experimental characterization 257
Expert Committee 120
Expert Committee on Food Additives 124
Expert Consultation 122
expert opinions 108, 111, 117
Expert Systems 537
expiry date 441
expiry products 457
exploding fridges 493
exploitation, integral 244, 252
exploration 189
exploratory study 536
exporter 300
exposition 236, 239
exposure 105–6, 110, 112–13, 117, 156, 205, 231, 237–8, 241–2, 257, 281, 354
Exposure assessment (EA) 106–7, 112–15, 121–3, 261
  acrylamide 114
  chemical 113, 117

Exposure assessment (EA) (*Continued*)
  cyclic 250
  direct 113
  following 107
  given less public 511
  hour's 371
  indirect 114, 120
  level of 115–16
  limited 104
  magnitude of 112–14
  possible 113
  potential 105
  short-term 260
  toxic 473
exposure assessment (EA) 106–7, 112–14, 121, 261
  dietary 114
exposure control 116
exposure level, safe 117
exposure pathways 113
exposure procedure 113
exposure routes 112, 114
exposure time 114, 228, 280–1, 283–5, 489
  long 284
exsanguination 181–2
Extended Producer Responsibility (EPR) 341
extensions 70, 104, 221, 226, 324
  planned 304
external resistance 396
  negligible 396
extract composition 309
extract lycopene 245
extraction 245, 271–2, 287–8, 296–9, 475
  enzyme 210
extraction procedure 556
extraction techniques 249, 299
extraction time 272
extracts 237, 246, 250, 272, 296, 475, 488, 556
  crude 245
  fermentable 302
  pomegranate pulp 259
  rice bran enzymatic 293
  using phenolic-enriched 245
  vegetable byproduct 259
extracts of coffee 385
extrapolation 28, 111, 115
extrapolation studies 112
extrinsic factors 282
extrusion 270, 314

facial image 530
facial recognition technology 530
facilitation 526, 532
facilities 178, 181, 207, 212, 327, 349, 377, 448, 465, 478, 486
  anaerobic 448
  commercial broiler processing 433
  commercial catering 208, 478
  large animal production 45
  rainwater-harvesting 154
  relatively large production 300
Facilities Engineers and Plant Managers 399
factor sourcing 526
factories 63, 77, 151–2, 157–8, 180, 212–13, 221, 223, 324, 329, 365, 406, 420, 427, 486–9
  designed 222
  food-processing 489
  fresh-cut 222
  ice cream 157
  industrial 222, 249
  large 136
  new 418
  total 488
  zero water 153
factory automation 536
factory floor 328
factory level 417, 423
factory personnel 301
factory ship 84
factory vehicles 159
factory vessels 200
facultative 409
faeces 95, 175
failures 104, 453, 464, 517
failures of home delivery services 214, 491
fair share 5
Fair Trade Coffee 309

Fair Trade Foundation 21
fair trade movements 319
fair trade policy 116, 301
false perception 426
family Saccharomycetaceae 373
fan 2, 11, 36, 231, 236, 238, 255, 300, 309
fan motors 471
  electronic commutated 471
fan speeds 489
farm 19, 23, 66, 82–3, 109, 111, 117, 120, 132, 158–9, 174, 221, 275, 506–8, 510–14
  individual 513
  neighbouring 46
  single 512
farm activities 153
farm animals 384
farm conditions 275
farm costs 60, 519
farm gate 86, 509–10
farm level 301, 530
farm life 530
farm site 505
farmed fish 197
farmer education 551
farmers 3, 275, 296, 315–16, 319, 456, 459
  helping 158
  international 552
farming
  commercial 318
  intensive 319
  organic 59, 102, 519
  organic sheep 50
farming and food strategy 500
farming communities 319
farming cooperatives 319
farming foresight study 19
farming practices 331
  intensive 318
farming region 102
farming systems 28, 54, 88, 546
  integrated arable 517
  organic pig 50
fat 24, 36, 44, 68, 134, 140, 142, 145–6, 151, 175, 177–9, 184, 314–15, 320, 322
  excess 179
  saturated 550
fat droplets 141
fat fryers, deep 466
fat globule size distributions 165
fat globules 141, 149
  small 141
fat-rich products 151
fat trimmings 180
fatty acid composition of melon 250
fatty acids
  omega 26
  saturated 327
  unsaturated 177
fatty acids linoleic 247
feasibility 244, 304, 311, 389, 408, 412, 469
  technical 421
  technological 116
feasibility assessment 423
feature, special 383
Federal Register 253, 255
feedback 106, 332
feedback inhibition 243
feedback loop 205
feeding 122, 460, 554
  cows 145
  wet 449
feedstocks 147, 287
feedwater 138
fermentation 25, 140, 142–3, 167, 225, 243, 288, 297, 303, 306, 313, 389
  anaerobic 241–2
  ethanol 555
  solid state 309
fermentation process 142, 373
fermentation stage 142
fermentation tanks 301, 404
fermentation temperature–time 142
fermented milk products 140
fermented products 147, 177, 384
fermented sausage 177
fertilizer 50, 76, 82, 182, 210, 296–7, 300, 445
  chemical 297

fertilizer production 76
fibre production 42–3
fibres, plant-derived 341
fibril dispersions 164
fibril morphology 164
filler 351
fillet 207, 486
  frozen 207
filleting 84, 202–3, 416, 487–9
filleting line 487
film area 226
film dries 139
film process production 351
film production 351
film selectivity 226
films 137, 139, 233, 342, 363
  agro-based 342
  barrier 241
  based nanocomposite 349
  complex 226
  conventional 226
  conventional non-perforated 226
  dried 139
  high-barrier 241
  micro-perforated 255, 256
  microporous 226
  petroleum-based 342
  polymeric 226
  using low permeability 241
filtration 31, 370, 394, 409–10, 415
  mash 302
filtration particle removal 409
final distribution 508
Final Effluent Limitations Guidelines and Standards 193
final washing 181
final water rinsing 422
financial burden 535
financial gain 525
financial support 249
financial targets 522
fingerprint 531
finished form 406
finished product 143, 212–13, 246, 355, 365, 373, 379, 404, 486, 491
  branded 315
finished rice product 270
finished wine product 373
firmness 142, 236, 242
firms, multinational 441
first-expired-first-out (FEFO) 528
first-in-first-out 528
fish 26, 44, 74, 84, 91, 95, 111, 114, 182, 197, 201–3, 208–13, 416, 486–9, 547
  behaviour 217
  bones 95
  chilled 487
  cold chain 217, 495
  commodities 206
  consumption 83
  dried 384
  exposed 489
  flesh 95
  fresh 207
  harvesting stage 83, 197
  individual 202
  industry 122, 486
  Fish Industry Authority 218
  markets 212
  meal 84, 210, 384
  oil 210, 211, 483
  packed 488
  paste products 218
    white 204
  pond 304
  preserved 384
  preserving 205
  processing 210, 218, 421
  processing chain 197
  processing sectors 421
  production 213
  products 84, 201
  protein 210
  protein hydrolysate 210
  samples 111
  sector 384
  smoked 109
  stocks 205
  storing 200
fisheries 51, 58, 200, 215, 217, 548
Fisheries, Marine 218
Fisheries Research 89, 218

Fishes 217
fishing 197, 215, 439, 445, 552
  fishing boats 211, 213
  fishing fleet 84
  fishing gear 211
  fishing operations 197, 201
  fishing vessels 197, 201, 216, 494
    large 201
    sized 197, 200
fishmeal 210
Five a Day initiative 24
five-day period 175
five-fold 208, 470
fixed compressed air leakage 386
fixed number 152
flaking equipments 187
flame, open 137
flavonoid biosynthesis 239
flavonoid contents 238
flavonoids 237, 240, 246
  including 245
flavonolquercetin 246
flavour compounds 141
flavourings 204
flavours 25–6, 132, 140–3, 210, 220, 243, 248, 296, 322
  smoked 185
  unami 25
flesh 236, 244, 265
  unused 244
flesh nectarines, white 245
flesh softening 243
flexible flow 459
flocculation 409
floor coverings 349
floors 95, 139, 175, 203, 371, 404
  thicker 212, 465
Florence 37
Florida 192, 252
flotation 300
  dissolved air 410, 415
flotation tank 301
flour 303, 314, 322, 385
  soybean 270
flow 72, 75, 78, 210, 286, 305, 366–9, 409, 505, 521
  concurrent 275
  fluid 364, 367–8
  minimum water 425
  physical 69
  pulsating 369
  state turbulent 369
  total mass 78
  transient 369
flow rates, high 203
flow restrictors 420
flow velocity 368
  relatively low 369
flow velocity field 367
fluctuations 315, 368
  local 368
flue gases 286
  hot 387
  stack 387
fluid 367, 368, 397
  low-pressure 397
fluid action 368
fluid ejection 396
fluid exchange 368
fluid exudation 223
fluid milk 128, 132–6, 138, 140, 153, 159, 166, 399
  packaged 132
  pasteurized 129, 135
  supplies 148
fluid phase 397
fluid stream 389
fluidized bed 485
fluidized bed dryers 275, 277, 281
  commercial 277
  well-mixed 279, 290
fluorescens 235
flux 421
  behaviour 431
  high 416
focus 2, 4–5, 12, 14, 17, 32–3, 65, 67–8, 70, 72–3, 78–9, 81, 86–7, 196, 500
  international 521
  significant 81
  small-scale 64
focus groups 461
fodder production 132, 161
foils 348–9

food
  animal 48
  available 50
  balanced 54
  canned 313–14, 390, 404
  cheap 3, 41
  chilled 442, 482–3, 494
  consumed 436
  consumer-led 35
  current 22, 316
  deactivating key 230
  deliberate 111
  developing 464, 490
  discarded 455
  edible 437
  enrich 547
  fast 442
  fatty 355
  fortifying 322
  fresh 455
  fresh-cut 248
  frozen 28, 211, 445, 476, 483
  healthier 149
  high risk 176
  higher quality 3
  household 462
  human 111, 119, 547
  imported 29
  improving 46
  improving water-intensive 402
  making 314
  manufactured 321, 545
  matter 170
  pet 217
  post-harvest 399
  producing gluten-free 315
  quality 500
  reduced-fat 149
  refrigerated 206, 475–6
  safe 6, 40, 120, 463, 551
  sea 127
  solid 392, 396
  stable probiotic 165
  staple 322–3, 383
  supplying 316
  traceable 3
  transporting 477
food aid 53
Food and Agriculture Organisation (FAO) 49–50, 56, 89, 103–5, 107–8, 110–13, 115–16, 118–20, 122–3, 190–1, 215, 334, 438, 548–9, 554
  estimates 179
  expert consultation 37
  fisheries 215
  international symposium on Dairy Safety and Hygiene 167
  perspective 191
  Rome 122
  STAT 36
  statistical database 56
Food and Drink Federation 445, 459–60
Food and Drug Administration (FDA) 224, 229, 234, 255
food animals 482
food applications 166, 299
food availability 52, 440
Food Banks 456
food businesses 33, 549
food chain 3, 6, 40, 56, 65, 81, 84, 86–7, 89, 103–17, 120–2, 182, 270, 518
food chain integrity 536
food choices 18, 47, 88, 105, 329, 543–4, 551, 554–5
food commodities 114, 383
food companies 17, 22, 27, 29, 127, 161, 324, 326–7, 330, 440
  multinational 321
food components 40, 62, 240
food composition 236, 258, 331
food constituents 232
food consumption 4, 7, 11, 48, 53–6, 188, 335, 438, 539, 542, 544–6, 550, 554
  ethical 552
  projected 543
  total 48
food consumption patterns 91, 191
food consumption trends 36
food contaminants 124
food crisis 119
food culture 17

food demand, manufactured 15
food distribution 50, 500
  national 502–3, 505, 507
Food Distribution and Consumption 497
food distribution chain 355
food drying 394, 398
food factories 154, 213, 418, 433, 485–6
food grain processing 6
food grains 42, 274–5, 277
food group 110, 116
food habits 52, 454
food handlers 222
food hazard assessment 365
food hazards 105, 187
Food Home Delivery 519
food hygiene 408
food industry 5–7, 24–7, 39–40, 43–6, 51–4, 332–6, 363–70, 373–5, 377–83, 385–90, 397–9, 403, 405–9, 418–20, 426–9
food industry manufactures products 438
food industry ozone 369
food industry ranks 377
food industry stakeholders 407
food industry standards 408
food industry sustainability strategy (FISS) 19, 35, 334, 405, 407, 430, 492, 500, 517
food industry waste 60
food ingredients 14, 245, 263, 288
  value-added 267
food insecurity 324, 541
food intake, recommended 50
food irradiation 267, 392, 400
food items 356, 361, 392, 396, 441
food labelling 325
  low-fat 88
food labels 34
food losses 40–2, 52, 355–6, 361, 464, 548
  addressing America's 461
food manufacture 31, 443, 475
food manufacturers 19, 104, 118, 314–15, 317, 320, 325, 327, 351, 390, 443, 466, 551–2
food manufacturing 7, 18–20, 24–5, 34, 314, 317, 319, 327, 331, 335, 382, 435, 443
  modern 325
  specialty 382
  stimulated 17
food manufacturing companies 20
food manufacturing decisions 326
food manufacturing efficiency 496
food manufacturing industry 329, 378, 380, 389, 443
food manufacturing operations 5–6, 433
food manufacturing processes 33, 443
food manufacturing requirement 22
food manufacturing sectors 31, 382–3, 443
food materials 356, 359
food matrix 246
food miles 22, 37, 45–6, 60–2, 127–8, 215, 332, 477, 499–3, 507–9, 511, 513, 515–17, 519–20, 545
  local 508
  validity of 214, 491–2
food packages 348
food packaging 6, 40–2, 58, 71, 87, 150, 166, 257, 340–41, 348–9, 359–60, 455
  designing sustainable 354
  intelligent 254
  processed 85
  secondary 302
food packaging operations 151
food packaging professionals 358
food packaging sales 358
food packaging sustainability 359
food packaging systems 52
food poisoning 51, 202, 211, 464, 481–3, 490–91, 494, 551
food policies 19, 28, 55–6, 60, 121, 165, 517, 519, 554
  international 121
  new 118
food preferences 540
food preparation 24, 29
food preservation 215, 390, 399, 493
  refrigerated 399

food-preservation technologies 90
  alternative 259, 399
food prices 42, 541, 551
food process equipment 367
food processes 377–8
  intensive 397
food processing 3–5, 14–15, 17–18, 30–3, 39–52, 62–5, 81, 85–7, 94–5, 127, 332–4, 373, 377–80, 400–2, 412–14
food-processing 257
  based 364
  commercial 314, 330
  contemporary 314
  fluid 372
  impacts 5
  measuring efficient sustainable 22
food processing equipment 234, 366–7, 370, 371
food processing facilities 252, 367, 377–8, 381, 385, 387, 389–90, 393, 400
food processing industry 4, 33, 40, 42–4, 50–1, 54–6, 315, 349, 378, 380, 389, 397, 401, 403, 406
food processing plants 43, 363, 387, 405
food processing sectors 7, 25, 397
food processing surfaces 369
food processing systems, developing sustainable 68
food processing wastes 43, 389–90, 415
food processors 3, 12, 15, 17, 22–3, 26, 118, 239, 426
  sanitation programmes 364
food producers 1–2, 88, 94, 99, 104–5, 117, 316, 447
food production 2–3, 5–6, 12, 15, 37, 42, 46, 50–1, 56, 103–4, 107–8, 318–21, 500–501, 539–40, 549–50
  sustainable 60, 88, 103–4, 119, 545
food production systems 5–6, 19, 26, 94, 99, 104–5, 107, 316
food products
  eco-design 38
  high quality 85
  higher-value 378
  manufactured 12
  manufacturing of 11, 407
  sustainable 54, 545
food quality 36, 42–3, 46, 253, 259, 262, 264, 290
food refrigeration 396, 400, 474, 483, 490, 493
food refrigeration applications 496
food refrigeration operations 216, 486, 494
food refrigeration processes 480
food retail 474, 484
food retailers 457
food retailing 518–19
food safety 36, 46, 51–2, 54–7, 61, 82, 104–6, 110, 116, 118, 120, 122–3, 175–6, 261–2
Food Safety Guidelines 258
Food Safety Inspection Service 266
food safety issues 252
food safety organizations 121
food safety policy makers 120
food safety problems 116, 408
food safety regulations 104, 405
food safety risk analysis 122
food sector 18, 66, 128, 186, 215, 289, 382, 426, 485, 492, 516, 518
food security 3, 7, 12, 15, 19, 36, 40, 53, 62, 103–4, 122, 165, 317, 540–41, 554–6
  dimensions of 541
  improving 46
  including 121
  sustainable 15
  threat of limited 2, 11
food security complement 94
food security implications 13
food security indicators 541
food security policy 57
food security situation 15
food self-sufficiency 46, 58, 553
food service sector 24, 315, 443
food shopping 206, 214, 477, 491, 503, 517
food sources 48, 323
food spoilage 51, 211, 390, 445, 464, 490
food standards 36, 122
Food Standards Agency 25, 36

Food Standards Programme 122–3
food supply
  global 101
  nutritious 321
  safe 87, 331
  sustainable 3, 24, 105
food supply chains 7, 11, 15, 18, 20, 23–4, 28–9, 32–3, 45, 335, 435, 437, 439–40, 453–4, 548
  frozen 30, 217, 495
  industrial 28
  perishable 462
  reliable 3
  sustainable 34, 336
food surplus 460
food system 2, 11, 14–15, 17, 19–21, 27–9, 31, 34, 38, 50, 52–3, 56, 113, 120, 508–509
  alternative 499
  competitive 19
  global 13, 27, 435
  local 509
  sustainable 14, 19, 21, 316, 333
food system sustainability 2, 4
food terrorism 105, 111, 117
food traceability 104, 536
food trade 46
  international 53
food transport 379, 476, 509
food transport accounts 476
food trimmings 443
food types 46
food unit 176
food waste 2, 4, 15, 34, 40–2, 43, 57–9, 87, 355,435–8, 440–43, 446–9, 451, 453–61, 548–51, 554–6
  avoidable 455
  direct 43
  domestic 34
  organic 43
  reducing 549
foods industry 336
foodstuffs 63, 188, 245, 446
  perishable 213, 463
footprint 33, 70, 143, 204–5, 515
  minimizing 129
footprinting, environmental 21
forecast 450, 452, 535
forecasting 33, 37, 443, 450, 452, 454, 458
forecasting error 450
formation
  biofilm 160, 233, 238, 367
  cyanide 411
mycotoxin 280
  particulate matter 287
  photo-oxidant 79
  photochemical oxidant 287
  potential 230
  residue 372
fossil fuel depletion 287
fossil fuels 82, 157, 161, 174, 176, 178, 181–2, 197, 206, 287, 300, 326, 476, 500, 505
  total 151
fossil fuels consumptions 307
fouling behaviour 421
framework
  architectural 522
  basic 341
  conceptual 537
  harmonized 86
  methodological 64, 91, 101
  theoretical 65
framing policy 117
franchisees 504–5
free chlorine content 234
freezers
  existing spiral 466
  first contact 203
  immersion 203
  low temperature blast 201, 467
  modern cryogenic 204
freezing fishery products 216
freezing guidelines 216, 494
freezing methods 203
freezing operations 202, 390
freezing plants 187
freezing pretreatment 295
freezing seafood 203
freezing tunnels 203, 395, 398
frequency, increased 52
frequency of occurrence 109
fresh characteristics 243

fresh-cut baby spinach 263
fresh-cut bell peppers 242, 253
fresh-cut by-products 244–5
fresh-cut industry 221, 244, 247, 254, 258
fresh-cut lemons 223, 252
fresh-cut lettuce 234, 237–8, 242, 255, 260, 262
fresh-cut mangoes 238
fresh-cut peppers 253
fresh-cut plant commodities 221, 228, 248–9, 251
Fresh-Cut Produce Industry 258
Fresh fillets 384
fresh fruits 220, 225, 252, 255, 258, 263, 440–41
  processed 261
fresh mussel 84
fresh products 451
freshwater 84, 402
frozen cod fillets 91, 218
frozen cod production 209
frozen cooked rice 270
frozen fish 84, 207, 384, 486–7
frozen products 158, 451, 470
frozen storage cabinet 469
frozen storage rooms 487
frozen vegetables 384
fruit juices 262, 349–50, 390
fruit peel 236
fruit production 101
fruits, citrus 237, 256
fuel conservation 28
fuel consumption figures 508
fuel consumptions, total 386
fuel costs 200, 304
fuel demand, high 383
fuel efficiency 211, 213, 504, 516
  recorded 505
fuels
  boiler 381, 387
  combustion of 155, 378
  vehicle 507
fumigants 280–1
fumigation 290, 295
  chemical 280, 284
  traditional 279
fumigation of grain 289
fumigation requirements, long 280
functional foods 22, 244, 267, 293, 336, 544
functional ingredients 149, 160, 244
  new value-added 149
functional nanofibrils 148
functional unit 66, 71–2, 77–8, 98–9
functions 66, 71–3, 88, 99, 104, 150, 205, 238, 243, 255, 294, 297, 340, 359, 532–3
  basic 390
  biological 166
  environmental 65
  multiple 71
  social 65
fungal strains 299, 310
fungicides 107
furnace 286, 381
  box type 286
  husk-fired 286
  pot 286

γ-aminobutyric acid (GABA) 274, 292–4
  accumulation 274
  content 274, 292
    Thai aromatic 274
  increased brown rice 294
gamma irradiation 279, 281, 289–90, 295
  of rice grains 294
garlic 26
gas-air mixture 286
gas chromatograph mass spectrophotometry (GC-MS) 430
gas composition 225–6
gas concentrations 235, 281
  headspace 261
gas diffusion 226
gas emissions 175, 228, 234
  annual greenhouse 474
  anthropogenic greenhouse 318
  associated greenhouse 128
  direct greenhouse 318
  estimating greenhouse 504
  food system's greenhouse 19
gas-flushing 227

gas mixtures 241
gas-scavenging 227
gas tanks 304
gas turbines 485
gaseous energy products 389
gaseous O3 235
gases 72, 154, 214, 226–7, 234–5, 243, 278, 318, 491, 505
  concentrated 230
  exhaust 139, 389
  hydrogen 485
  unstable 372
  xenon 267
gases mixtures 243
gasification 389
  draft rice husk 286
gasification efficiency 287
gasifier 287
generations, aerosol 178, 181
genetic diversity 318
genetic modification 315, 336, 524
genetically modified (GM) 51, 55–6, 58, 60–1, 120, 123, 141, 321, 334
genetically modified animals 123
genomics 314, 320, 332
  functional 248
genotoxic 117, 122
German purity standards 303
germinated brown rice (GBR) 45, 271, 274, 291–3
germination 45, 271, 274, 279–80, 303
glass 41, 85, 107, 151, 348, 350, 446
  recycled 349
glass bottles 73, 151, 348
  disposable 42
  production 304
  refillable 350
glass containers 348
global agriculture 37, 122
global compact's (GC) 407
global dairy agenda for action on climate change 161, 163
global environment 60
global environmental policies 60
global food security 3, 37, 52, 103–4, 120, 460, 496, 540–41, 545, 556
global good agricultural practice 36
global population 3, 16, 42, 102, 148, 547
global warming potential (GWP) 20, 31, 78–79, 196, 201, 356–7, 473
glucosinolates 246
glutamic acid 247, 298
glutathione 177
glycoalkaloids 107
good manufacturing practice (GMP) 104, 222, 254
goal
  food business 21
  food sustainability 13
  immeasurable consumption 13
  socio-economic 553
good agricultural practice (GAP) 36
good hygiene practice (GHP) 104
good manufacturing practice (GMP) 104, 222, 254, 289
government regulations 30, 130, 379, 553, 556
government's labelling system 507
grain by-products 290
grain processing 270, 274, 285
grain protection 279
grains
  cereal 288
  dried 286, 288, 293
Gram-negative cells 229
granular activated carbon 309
GRAS antimicrobial substances 248
gravity separation 404
grazing 29, 169, 331
green beans 29
  frozen 29
green brewery 305
green brewery concept 305, 310
green tea 42, 58, 246, 254
greenhouse 46, 51, 214, 491
  current 174
  heated 545
green house gas (GHG) 12, 28, 46, 50, 61, 173–5, 302, 438, 543, 545
  emissions 2, 12, 15, 18, 21, 26, 28–30, 33, 39, 41–4, 49–51, 54–5, 58, 61, 80, 82, 83, 88, 127–8, 130, 132, 150, 170, 173–6, 183, 184, 186, 188, 196, 302, 318, 354, 448–9, 546

green house gas (GHG) (*Continued*)
abatement, including 19
mitigating agricultural 176
reduction measures 33, 59
total 475
footprint 90
mitigation 35
nitrous oxide 546
taxes 193
greenhouse tomato production 59
groups
age 48
environmental 474, 524
gross domestic production (GDP) 53, 173, 437
gross material intensity (GMI) 354
growth
bacterial 234, 239, 420, 466
economic 2, 11, 191, 547, 550, 553
inhibited 242
pathogen 239
growth of fungal strains 310

habitual purchase behaviour 544
hams 173, 183, 185
cooked 177
hard red winter wheats 294
harvest 20, 196, 223, 318, 475
temperature post 475
harvest date 221
harvest equipment 248
harvest techniques 551
harvested products 248
harvesting 40, 154, 197, 221, 228, 275
rain water 162
harvesting machines 331
harvesting methods 547
hazard analysis 221, 265
hazard analysis and critical control points (HACCP) 104, 221, 258, 413, 418, 427, 429
approach 429
plans 418–20
principles 364, 416
programs 408
system 420
team 418
hazard characterization (HC), 107, 112, 114
hazardous 422, 448
hazardous materials 113
hazards 104–8, 110–14, 117, 120–1, 308, 343, 357–8, 365
chemical 107, 110–11
foodborne 120
human 111
most significant 108
particular 109
physical 107–8, 111
potential 104–5, 107, 113, 115
health
ecosystem 316
improving 215, 492
material 357–8
national 59, 111
nutritional 175
occupational 343, 348
health claims 322
health consciousness 47
health effects, adverse 106–7, 109, 115
heat exchange 86, 278
high-temperature 391
low-temperature 391
heat exchange networks 429, 432
heat exchangers 153, 160, 164, 363, 387–8
efficient 82
fouled 136
tube type 137, 140
heat loss 136, 138, 489
cumulative 136
heat processing, conventional 404
heat pump 278, 386, 389–91, 394–5, 398–9
heat pump cycle 391
heat pump dehumidifier 394
heat recovery 129, 278, 393
latent 278
optimized 305
heat regeneration 135
heat transfer 136, 203, 396
heat transfer coefficient 475, 489
heat transfer efficiency 136, 138

heat treatment process 142
heating
dielectric 281
microwave 392
radiant 281
heating medium 129, 135, 137, 139
high BOD 176, 182, 416
high BOD and COD levels 44
high CO_2 levels 241, 243
high-density polyethylene (HDPE) 355
high-grade proteins 177
high O_2 atmospheres 241–2
high oxygen atmospheres 266–7
high-pressure jet 397
high pressure processing (HPP) 42, 58, 282, 290, 292, 391
high protein food 303–4
high risk 436
high temperature short time (HTST) 129, 135, 392
pasteurizer 135
higher BOD removal efficiencies 45
higher operational costs 412
homogeneity requirements 85
homogenization 132, 134, 141, 160
homogenizers 136
horse power (HP), 276, 282, 301
horticultural products 460
hot drying air 139
household waste 443, 450, 452, 455, 458
high temperature short time (HTST) 129, 135, 392
HTST pasteurizer 135
Hue 301, 309
human activity 316–17
human activity impacts 1
human behaviour 52
human consumption 50, 108, 134, 148, 173, 187, 189, 231, 247, 253, 255, 270, 281, 436–7, 548–9
human health 1, 59, 64–5, 78, 95, 99, 105, 108, 113–14, 117–18, 120, 185, 188, 219, 501
human rights 21, 540, 553
human–animal relations 191
humid conditions 481
humidity
controlled 370
relative 205
Hurdle technologies 259
HVAC 381, 386
hydrocarbons 474
hydrochlorofluorocarbons (HCFCs) 473
hydrodynamics 367–8
hydrogen peroxide 156, 233, 238, 255, 257, 259, 262–3, 266, 422
hydrolysis 364
hydrophobic 409
hydroxyl radicals 231
hygiene 139, 154, 156, 167, 176, 345, 429, 433
hygiene procedures 364

importance 6, 14, 17, 28, 29, 45, 98, 116, 137, 148, 149, 150, 152, 194, 245, 253, 300, 306, 326, 327, 337, 349, 367, 371, 402, 450, 468, 525
imports 172
increases in 274, 344, 477
incentives 156, 313, 414, 424
index 2, 35, 36, 56, 68, 123, 192, 244, 268, 269, 293, 396, 423, 426, 427, 455, 463
India 15, 16, 27, 147, 151, 152, 153, 155, 162, 171, 187, 335, 354, 434, 515
indicators 2, 28, 58, 88, 91, 96, 97, 98, 99, 100, 101, 112, 247, 293, 304, 315, 323, 325, 326, 329, 336, 337, 350, 351, 377, 379, 412, 423, 430, 449, 513, 537
indicators of 2, 28, 100, 315, 326, 412
indicators of sustainability 2, 28, 326
infrastructure 5, 27, 73, 272, 313, 324, 340
innovation 4, 14, 25, 27, 53, 86, 168, 293, 302, 316, 317, 321, 322, 325, 327, 330, 349, 357, 424, 426, 514, 519, 549
insecticides 106, 276
institutional 15, 186, 549
institutions 163, 222, 423, 518, 535
integrated pest management 219

interactions 4, 223, 224, 237, 246, 273, 311, 319, 339, 445, 450, 523, 529
interpretations 120, 312, 329

justice 3, 99, 505

knowledge 14, 19, 71, 88, 103, 106, 118, 154, 187, 287, 304, 316, 318, 325, 327, 360, 414, 420, 450, 451, 464, 514, 519, 521, 522, 524, 529, 536, 539, 540, 548, 551
Kuwait 335

labour 92, 168, 185, 295, 316, 326, 368, 377, 378, 433, 449, 521, 525, 548
land 12, 14, 15, 20, 21, 26, 28, 29, 37, 40, 43, 50, 57, 64, 68, 79, 97, 102, 150, 170, 173, 188, 203, 204, 205, 295, 296, 303, 314, 327, 339, 345, 351, 443, 444, 471, 473, 500, 509, 513, 542, 548, 552
Latin America 538, 539, 542, 544
learning 518, 519, 530
linkages 289, 291
livestock farming 542
local communities 153, 518
local economies 316

Malaysia 286
management practices 53, 291, 298, 381, 416, 431, 439, 445, 448
manure 66, 76, 113, 177, 178, 181, 226
marketing 14, 24, 32, 34, 67, 71, 226, 311, 319, 320, 321, 325, 326, 327, 335, 349, 352, 437, 446, 448, 449, 520, 521, 529, 539, 548, 549
markets 18, 24, 32, 43, 46, 52, 69, 85, 187, 190, 206, 210, 225, 307, 310, 311, 315, 330, 439, 452, 469, 473, 475, 519, 522, 525, 541
materials 1, 3, 20, 25, 41–44, 50, 51, 52, 53, 54, 58, 63, 71, 72, 76, 77, 85, 93, 94, 106, 110, 126, 131, 148, 149, 150, 180, 183, 185, 186, 188, 189, 190, 202, 208, 210, 219, 225, 245, 247, 250, 271, 276, 280, 282, 293, 295, 296, 298, 300, 317, 326, 327, 328, 335, 336, 337, 338, 339, 340, 344, 345, 346, 349, 350, 351, 352, 353, 354, 355, 356, 359, 372, 377, 409, 411, 432, 439, 442, 443, 456, 461, 463, 471, 482, 484, 486, 487, 521, 536
Meadows 290
measuring sustainability 520
media 134, 148, 239, 285, 317, 330, 377, 392, 423, 450, 505
methodology 29, 63, 64, 68, 69, 70, 75, 81, 86, 88, 90, 94, 105, 276, 301, 347, 350, 357, 450, 457, 504, 520
motivation 52, 529

National Academy of Sciences 35, 492, 552
National Environmental Policy Act (NEPA) 96
National Renewable Energy 77
natural environment 93
natural gas 156, 376, 502
natural resources 6, 27, 40, 93, 98, 130, 159, 185, 190, 424, 434, 435, 536, 537
natural capital 35, 65, 513
nature 5, 15, 68, 95, 106, 107, 111, 112, 114, 115, 147, 160, 198, 300, 312, 322, 325, 367, 420, 447, 457, 496, 514
negative externalities 497
Netherlands 100, 156, 159, 163, 164, 175, 255, 330, 375, 379, 380, 427, 429, 478, 491
networks 7, 296, 313, 315, 328, 385, 404, 425, 426, 428, 504, 515, 517, 518, 519, 520, 521, 522, 529
North America 41, 345, 398, 444
Norway 82, 205, 444
Network 18, 38, 58, 190, 427, 489
Nevada 374
Newcastle 99
Nicaragua 99
Nigeria 305, 434
non-renewable 39, 68, 337, 535, 546
North Sea 215
Norway 82, 205, 444

optimization 28, 71, 137, 148, 164, 261, 263, 275, 287, 301, 354, 383, 384, 386, 389, 391, 416, 419, 420, 421, 426, 428, 429, 482, 551
organic farming 101
oil 26, 58, 72, 84, 93, 142, 144, 145, 154, 156, 174, 208, 245, 248, 250, 262, 266, 267, 268, 269, 295, 304, 323, 331, 372, 379, 380, 385, 403, 411, 501, 508, 514, 542
Orlando 490
Oxford University 162, 192, 356

participation 95, 99, 322, 324
participatory processes 322
pesticides 50, 106, 409, 497
Philippines 215, 289, 291, 292
philosophy 87, 170, 188, 215
policies 18, 43, 103, 116, 120, 154, 158, 169, 185, 335, 362, 402, 403, 413, 446, 449, 450, 451, 455, 498, 522, 535, 548
policy options 45
politics 514
population 2, 3, 6, 11, 12, 13, 14, 15, 16, 24, 26, 40, 42, 46, 92, 95, 98, 101, 102, 103, 112, 113, 114, 126, 147, 152, 160, 164, 169, 172, 187, 222, 229, 234, 236, 262, 267, 280, 318, 319, 328, 397, 402, 434, 451, 460, 468, 490, 535, 536, 539, 541, 542, 543
practical approaches 409
prices 36, 42, 52, 62, 74, 154, 186, 375, 393, 424, 453, 454, 537, 545, 547, 549
production of food 21, 34, 328
production sustainability 92
programme 62, 91, 121, 122, 189, 192, 206, 214, 215, 287, 289, 291, 398, 434, 457, 458, 474, 478, 490, 492, 551
project 37, 55, 57, 62, 77, 79, 80, 89, 95, 99, 100, 168, 191, 213, 247, 404, 471, 472, 477, 488, 491, 492, 513, 551

realities 321
research 11, 19, 22, 23, 24, 29, 32, 33, 34, 36, 57, 62, 78, 106, 140, 141, 142, 146, 149, 159, 160, 161, 188, 189, 205, 219, 220, 224, 229, 232, 233, 236, 239, 242, 245, 246, 247, 252, 256, 259, 274, 284, 310, 315, 316, 321, 327, 329, 336, 347, 354, 422, 423, 424, 431, 434, 439, 448, 449, 455, 458, 464, 490, 498, 507, 524, 526, 528, 533, 541, 548
reservoirs 152, 181
responses to 81, 111
rice 13, 39, 42, 45, 51, 55, 58, 60, 61, 88, 156, 267, 268, 269, 271, 273, 274, 276, 277, 278, 279, 280, 281, 282, 283, 284, 286, 287, 288, 289, 290, 291, 292, 295, 298, 299, 306, 395, 436, 437
rural areas 437

science 5, 25, 34, 86, 104, 122, 149, 155, 159, 261, 316, 317, 331, 357, 430
services 19, 33, 35, 40, 52, 64, 70, 88, 102, 129, 151, 168, 169, 188, 189, 204, 212, 253, 313, 330, 331, 426, 438, 456, 473, 487, 491, 499, 513, 529, 533, 536, 549
social 1, 2, 3, 4, 5, 7, 17, 18, 21, 22, 23, 24, 29, 33, 42, 65, 93, 95, 98, 101, 103, 104, 114, 119, 126, 157, 161, 172, 185, 186, 266, 312, 313, 315, 317, 319, 320, 321, 323, 325, 326, 327, 328, 329, 330, 331, 335, 340, 355, 377, 403, 422, 428, 431, 433, 434,449, 454, 496, 505, 512, 513, 518, 520, 535, 536, 539, 546, 550
social justice 4
social sustainability 185, 266, 315, 377
solar 43, 61, 154, 156, 303, 378, 393, 394, 395, 464, 481, 487, 492
solar energy 154, 156, 303, 374, 393, 464
solar power 464, 481, 487, 492
solar thermal energy 43, 61
solid 31, 43, 44, 55, 83, 85, 94, 100, 126, 141, 172, 179, 181, 182, 183, 184, 185, 202, 208, 295, 296, 305, 316, 346, 381, 385, 388, 392, 393, 394, 400, 409, 443, 451, 455, 457

solid waste 43, 55, 83, 94, 100, 126, 172, 179, 182, 316, 346, 443, 451, 455, 457
spills 208, 362
spread of 107, 123
Sri Lanka 152, 163, 379
standards 12, 24, 36, 37, 46, 104, 121, 129, 130, 165, 264, 299, 322, 324, 325, 326, 328, 331, 338, 349, 361, 404, 412, 422, 424, 436, 441, 450, 473, 541, 542, 544, 549
stewardship 336, 354
strategies 7, 17, 18, 22, 26, 27, 42, 50, 54, 60, 61, 91, 103, 105, 116, 117, 127, 128, 130, 140, 150, 158, 159, 161, 185, 187, 188, 208, 246, 274, 294, 315, 322, 330, 340, 345, 349, 360, 361, 401, 403, 404, 409, 411, 413, 414, 416, 436, 454, 517, 519, 521, 539, 548
structure 5, 28, 63, 119, 139, 144, 148, 149, 170, 209, 211, 219, 225, 232, 237, 279, 360, 375, 436, 437, 442, 463, 484
subsidized 156
summit 102, 121, 550
supplies 46, 102, 147, 201, 309, 319, 322, 327, 329
sustainability issues 6, 127, 190
support services 424
sustainability concepts 6
sustainable agriculture 495, 515
sustainable development 20, 62, 100, 213, 215, 404, 516, 546, 550
Sweden 55, 82, 88, 89, 162, 213, 292, 356, 445, 456, 488
Switzerland 55, 59, 382, 398, 478
system 65, 72, 89, 212, 329, 330, 335, 339, 487, 490, 504, 551

technologies 4, 27, 30, 31, 32, 33, 42, 43, 50, 54, 88, 90, 91, 102, 131, 133, 139, 142, 146, 147, 148, 149, 152, 153, 155, 157, 158, 159, 160, 161, 164, 166, 175, 212, 219, 227, 249, 252, 256, 257, 260, 302, 304, 310, 311, 316, 317, 318, 321, 372, 375, 381, 384, 386, 387, 390, 393, 395, 402, 404, 409, 411, 413, 414, 417, 424, 428, 443, 460, 479, 482, 492, 518, 521, 522, 524, 525, 526, 530, 545
training 325, 336, 416, 422, 453, 545
transitions 13, 15
transport 4, 22, 30, 46, 66, 71, 72, 82, 83, 84, 85, 94, 95, 140, 158, 168, 195, 199, 204, 205, 209, 210, 213, 215, 224, 230, 279, 282, 310, 313, 314, 322, 324, 329, 335, 339, 344, 347, 350, 360, 375, 377, 378, 389, 400, 460, 463, 464, 472, 473, 476, 479, 481, 483, 487, 489, 492, 496, 499, 500, 503, 504, 505, 506, 507, 508, 509, 510, 512, 513, 514, 522, 523, 525, 542, 545
treatment systems 419
triple bottom line 518, 519, 530
trees 72

U.S. 37, 62, 105, 129, 251, 264, 292, 378, 396, 430
U.S. Environmental Protection 396, 430
ultra high temperature (UHT)-treatment of milk 135
uncertainties 105, 106, 107, 109, 111, 113, 114, 118, 313
Unilever 17, 37, 85, 153, 155, 156, 161
United Nations 1, 13, 37, 56, 59, 62, 102, 121, 122, 126, 165, 189, 190, 192, 206, 213, 215, 398, 402, 403, 404, 429, 430, 456, 492, 536, 550, 551, 552
utilities 29, 127, 132, 151, 157

variables 275, 305, 309, 313, 318, 325, 366, 507
vehicles 82, 157, 158, 204, 445, 450, 463, 464, 472, 499, 500, 503

Wal-Mart 354, 357, 437
waste management 17, 30, 43, 54, 55, 59, 72, 77, 81, 186, 192, 288, 315,

347, 355, 356, 431, 439, 442, 455, 457, 519
waste reduction 158, 451, 452
water management 153, 157, 304, 397, 402, 403, 412, 413, 414, 424
water conservation 401, 409, 413, 414, 416
water heating 381
water pollution 56, 173, 430, 497
water supply 402, 414, 542
wildlife 246
wisdom 205, 320, 465, 505
wind energy 154, 156
World Bank 42, 172, 173, 183, 184, 186, 192, 398, 399, 401, 430, 434
World Health Organization (WHO) 15, 37, 46, 47, 49, 59, 62, 102, 103, 104, 106, 109, 110, 111, 112, 114, 115, 117, 119, 121, 122, 123, 198, 250, 539

zero carbon 211, 486